Semiannual water column monitoring report

February - June 2001

Massachusetts Water Resources Authority

Environmental Quality Department

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SEMIANNUAL WATER COLUMN MONITORING REPORT

February – June 2001

Submitted to

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the potential environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay, which occurred on September 6, 2000. From 1992 to September 2000, the data were collected to establish baseline water quality conditions. The current outfall monitoring is expected to provide the means to detect significant departure from that baseline. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area in the vicinity of the Outfall Site (nearfield) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semi-annual report summarizes water column monitoring results for the seven surveys conducted from February to June 2001.

Over the course of the HOM program, a general trend in water quality events has emerged from the data collected in Massachusetts and Cape Cod Bays. The trends are evident even though the timing and year-to-year manifestations of these events are variable. The winter to spring transition in Massachusetts and Cape Cod Bays is usually characterized by a series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. While this was generally the case in 2001, no major phytoplankton bloom was observed in Massachusetts Bay. There was, however, a winter/spring bloom of centric diatoms in Cape Cod Bay and a minor bloom of *Phaeocystis pouchetii* that was most prominent in northeastern Massachusetts Bay. With the lack of a major bloom, productivity and chlorophyll concentrations remained relatively low throughout this time period and surface waters across much of the region were not depleted with respect to nutrients until June.

Stratification was first observed in early April at Boston Harbor, offshore, and boundary stations. The development of stratification at these stations was driven by a decrease in surface salinity due to March/April runoff. In the nearfield, the water column also began to stratify by late March. However, stratification was confined to the deeper eastern nearfield stations. In early April, a localized mixing event was observed in the nearfield data. This may have been related to increased flow from the outfall discharge as a result of late March rain events. By late April, the water column had become weakly stratified across all of the nearfield area. Surface water temperatures had increased by >10°C throughout the bays by June, resulting in a strong density gradient throughout most of Cape Cod and Massachusetts Bays.

The nutrient data for February to June 2001 generally followed the "typical" progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring 'diatom bloom' in Cape Cod Bay surface waters reduced nutrient concentrations in February. In contrast, the minor winter/spring *Phaeocystis* bloom in Massachusetts Bay in early April did not lead to reduced nutrient concentrations except at boundary station F26 and F27 where the *Phaeocystis* abundance was highest. Massachusetts Bay nutrient concentrations decreased from early February through April, but did not reach depleted levels until June.

Ammonium concentrations continue to be a good tracer of the effluent plume in Massachusetts Bay. High effluent flow rates caused by late March and June rain events appear to have influenced water quality measurements in the nearfield at these times. In early April, the nearfield was less stratified than surrounding waters and elevated NH_4 concentrations were present in surface waters. In June elevated NH_4 (and PO_4) concentrations were measured in the surface waters suggesting that the plume had reached the surface. Neither salinity nor density data displayed an anomalous signal in these waters.

Chlorophyll concentrations were lower in 2001 than historically observed. The nearfield mean areal chlorophyll for winter/spring 2001 of 69 mg m^{-2} is well below the caution threshold of 182 mg m^{-2}. Chlorophyll concentrations peaked in early February and were highest in Cape Cod Bay coincident with the winter/spring diatom bloom. Chlorophyll concentrations increased and productivity peaked in the nearfield in early April, but there was no large increase in chlorophyll associated with the minor *Phaeocystis* bloom. The 2001 winter/spring peak production rates were considerably lower than winter-spring bloom maxima measured in 2000. Boston Harbor areal production peaked in June, but rates were lower than those measured during baseline monitoring.

DO concentrations in 2001 were within the range of values observed during previous years and followed the typical trends. Maximum concentrations occurred in February when the water column was well mixed. A slight increase in surface DO concentrations in April coincided with the peak in productivity. DO concentrations reached minima for this time period in June in most of Massachusetts and Cape Cod Bays. However, bottom water DO concentrations in June 2001 were higher than those measured during the two previous years. An increase in bottom water DO concentrations at the boundary stations from April to June is attributed to an influx of waters from the Gulf of Maine. The lack of a major winter/spring bloom in Massachusetts Bay and this regional influence of the Gulf of Maine led to the relatively high bottom water DO concentrations in June. The lowest bottom water DO concentrations over this February to June period were found in Cape Cod Bay, which is not strongly influenced by the Gulf of Maine and had a winter/spring diatom bloom in February.

Whole-water phytoplankton assemblages were dominated by unidentified microflagellates and several species of centric diatoms except during the April *Phaeocystis* bloom. This is typical for the first half of the year in terms of taxonomic composition. The *Phaeocystis pouchetii* bloom in April 2001 was much less abundant than the bloom of this species during the same period the previous year. The 2001 *Phaeocystis* bloom was also a departure from the 3-year cycle for these blooms that had been observed during the baseline period. There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during this time period, other than the April bloom of *Phaeocystis pouchetii*. While the dinoflagellate *Alexandrium tamarense* and the diatom of *Pseudo-nitzschia pungens* were recorded, they were present in very low abundance ($\leq$ 35 cells L^{-1}). The typical increase in zooplankton abundance from February through June was not observed in the spring of 2001, and zooplankton counts were considerably lower than observed for the same period the previous year. Moreover, the relatively low abundance of zooplankton may have been due to bottom-up control because phytoplankton was relatively sparse. Zooplankton assemblages during the first half of 2001 were comprised of taxa recorded for the same time of year in previous years.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) test for compliance with NPDES permit requirements; (2) test whether the impact of the discharge on the environment is within the bounds projected by the SEIS; and (3) test whether change within the system exceeds the Contingency Plan thresholds. A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA, 1997).

To monitor water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, the MWRA conducts ambient water quality surveys in Massachusetts and Cape Cod Bays. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area (nearfield) and a low-frequency basis for an extended area (farfield). The nearfield stations are located in the vicinity of the Massachusetts Bay outfall site (Figure 1-1) and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 1-2). The stations for the farfield surveys have been further separated into regional groupings according to geographic location to simplify regional data comparisons. This semiannual report summarizes water column monitoring results for the seven surveys conducted from February through June 2001 (Table 1-1).

Table 1-1. Water Quality Surveys for WF011-WN017 February to June 2001

Survey #	Type of Survey	Survey Dates
WF011	Nearfield/Farfield	February 7 – 9, 12
WF012	Nearfield/Farfield	February 27 - March 2
WN013	Nearfield	March 26
WF014	Nearfield/Farfield	April 4-6, 9
WN015	Nearfield	April 26
WN016	Nearfield	May 18
WF017	Nearfield/Farfield	June 19 – 21, 25

The bay outfall became operational on September 6, 2000. The seven surveys conducted during this semiannual period are the first winter-spring surveys conducted after discharge of secondary treated effluent from the outfall began. The data evaluated and discussed in this report focus on characterization of spatial and temporal trends for February to June 2001. Preliminary comparison against baseline data are discussed and appropriate threshold values presented. A detailed evaluation of 2001 versus the baseline period (1992-2000) will be presented in the 2001 annual water column report.

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted four times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy and electronic formats.

1.2 Organization of the Semiannual Report

The scope of the semiannual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the first seven surveys of 2001 (Sections 3-5). Finally, the major findings of the semiannual period are summarized in Section 6.

Section 3 includes data summary tables that present the major numeric results of water column surveys in the semiannual period by survey. A description of data selection, integration information, and summary statistics are included with that section.

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (Figure 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohassett, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional presentation of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outer most boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semiannual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly affects the temporal response of the water quality parameters, which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during pre-stratification stage (WF011 – WN013), the early stratification stage (WF014 – WN016), and once seasonal stratification was established (WF017). Time-series data are commonly provided for the entire semiannual period for clarity and context of the data presentation.

Productivity, respiration, and plankton measurements, along with corresponding discussion of chlorophyll and dissolved oxygen results, are provided in Section 5. Discussion of the biological processes and trends during the semiannual period is included in this section. A summary of the major water column events and unusual features of the semiannual period is presented in Section 6. References are provided in Section 7.

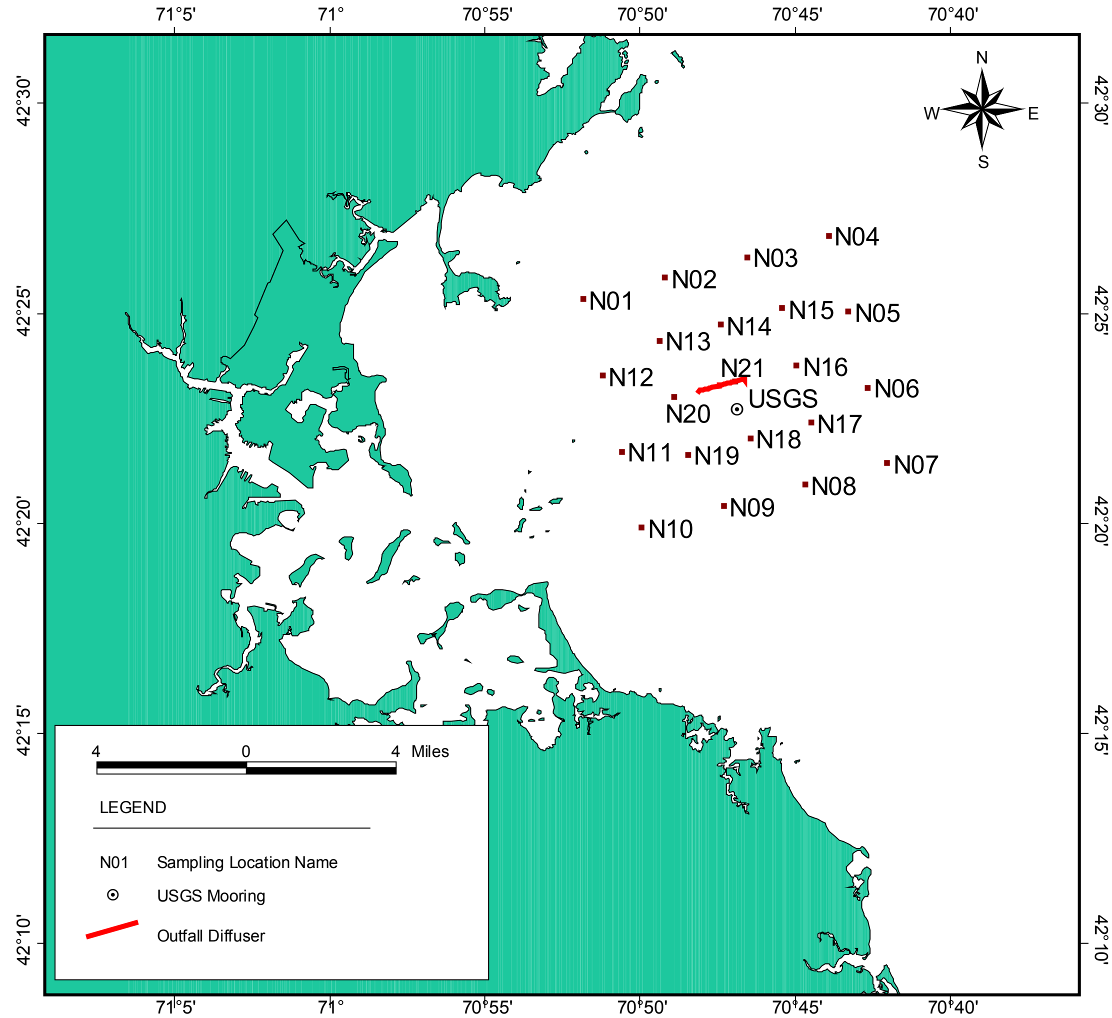


Figure 1-1. Locations of MWRA Offshore Outfall, Nearfield Stations and USGS Mooring

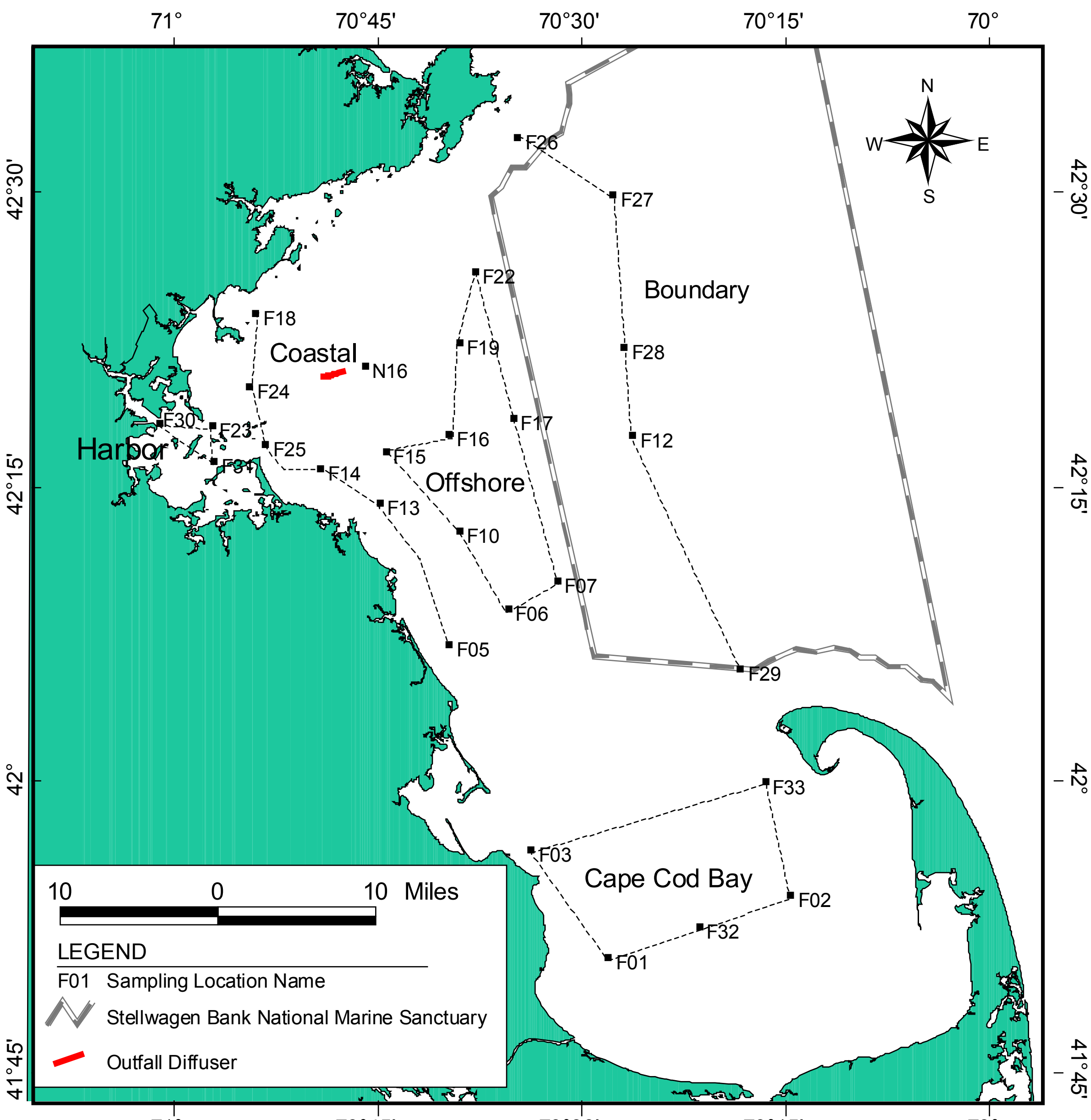


Figure 1-2. Locations of Farfield Stations and Regional Station Groupings

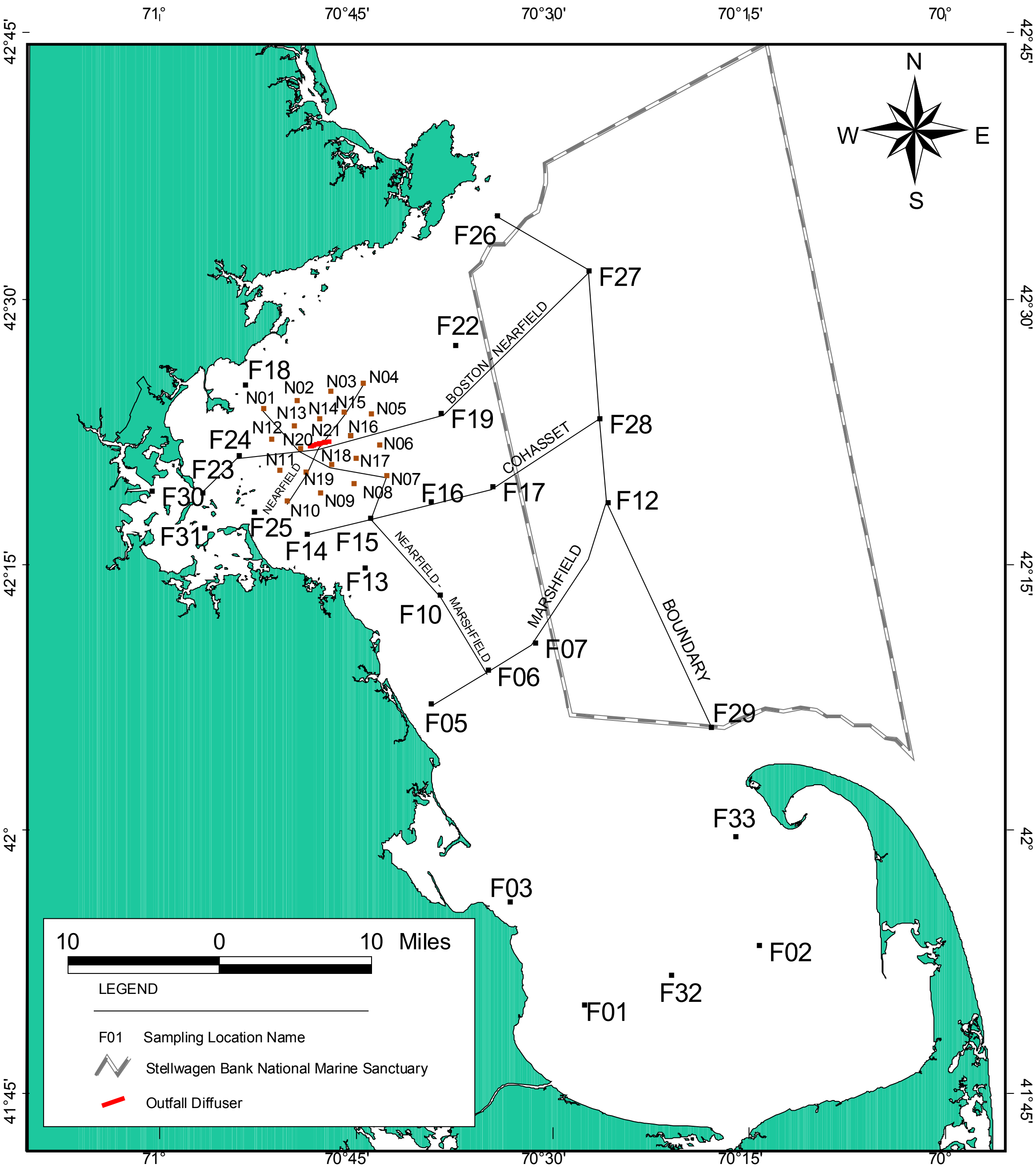


Figure 1-3. Locations of Stations and Selected Transects

2.0 METHODS

This section describes general methods of data collection and sampling for the first seven water column monitoring surveys of 2001. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for the first 2001 semi-annual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Albro *et al.,* 2002). Details on productivity sampling procedures and analytical methods are also available in Appendix A.

2.1 Data Collection

The farfield and nearfield water quality surveys for 2001 represent a continuation of the water quality monitoring conducted from 1992 - 2000. On September 6, 2000, the offshore outfall went online and began discharging effluent. The baseline monitoring period includes surveys from February 1992 to September 1, 2000. The last 5 fall 2000 surveys represented the beginning of the outfall discharge monitoring period, which continued in 2001. The data collected during outfall discharge monitoring are evaluated internally and against baseline data. Data collection methods and schema have not changed from the baseline to the outfall discharge water quality monitoring periods.

Water quality data for this report were collected from the sampling platforms *R/V Aquamonitor* and *F/V Isabel S.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Go-Flo bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station, except at stations F30, F31, F32, and F33. Stations F30 and F31 are shallow and require only three depths while only zooplankton samples are collected at F32 and F33. These depths were selected during CTD deployment based on positions relative to the pycnocline or subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 3 meters of the water surface) of each cast remained constant and the mid-bottom, middle and mid-surface depths were selected to represent any variability in the water column. In general, the selected middle depth corresponded with the chlorophyll maximum and or pycnocline. When the chlorophyll maximum occurred significantly below or above the middle depth, the mid-bottom or mid-surface sampling event was substituted with the mid-depth sampling event and the "mid-depth" sample was collected within the maximum. In essence, the "mid-depth" sample in these instances was not collected from the middle depth, but shallower or deeper in the water column in order to capture the chlorophyll maximum layer. These nomenclature semantics result from a combination of field logistics and scientific relevance. In the field, the switching of the "mid-depth" sample with the mid-surface or mid-bottom was transparent to everyone except the NAVSAM operator who observed the subsurface chlorophyll structure and marked the events. The samples were processed in a consistent manner and a more comprehensive set of analyses was conducted for the surface, mid-depth/chlorophyll maximum, and bottom samples.

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in Table 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen (PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to seven days until analysis.

2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see Table 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Table 2-1 lists the different analyses performed at each station. Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z).

Table 2-1. Station Types and Numbers (Five Depths Collected Unless Otherwise Noted)

Station Type	A	D	E	F	G[1]	P	R[4]	Z
Number of Stations	6	10	24	2	2	3	1	2
Analysis Type								
Dissolved inorganic nutrients (NH_4, NO_3, NO_2, PO_4, and SiO_4)	●	●	●	●	●	●		
Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1]	●	●			●	●		
Chlorophyll [1]	●	●			●	●		
Total suspended solids [1]	●	●			●	●		
Dissolved oxygen	●	●		●	●	●		
Phytoplankton, urea [2]		●			●	●		
Zooplankton[3]		●			●	●		●
Respiration [1]						●	●	
Productivity, DIN						●		

[1]Samples collected at three depths (bottom, mid-depth, and surface)
[2]Samples collected at two depths (mid-depth and surface)
[3]Vertical tow samples collected
[4]Respiration samples collected at type A station F19

2.3 Operations Summary

Field operations for water column sampling and analysis during the first semi-annual period were conducted as described above. Deviations from the CW/QAPP for surveys WF011, WF012, WN013, WF014, WN015, WN016, and WF017 had no effect on the data or data interpretation. For additional information about a specific survey, the individual survey reports may be consulted.

Table 2-2. Nearfield Water Column Sampling Plan (3 Pages)

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	0.1	1	1	1
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N01	30	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N02	40	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N03	44	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	4.5	1	1						1		1							1	1
N04	50	D+	3_Mid-Depth	22.1	2	2	1	1	2	2	2	2	2			1	1		1	6	1	1
		R+	4_Mid-Surface	4.5	1	1						1		1							1	1
		P	5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N05	55	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N06	52	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	10.5	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
N07	52	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	10.5	2	1	1	1	2	2	2	1	2	3								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N08	35	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N09	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N10	25	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N11	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N12	26	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N13	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N14	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N15	42	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	A	3_Mid-Depth	10.2	2	2	2	2	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N17	36	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																

Nearfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	1	1	1																
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
		D+	2_Mid-Bottom	4.5	1	1						1		1							1	1
N18	30	R+	3_Mid-Depth	26.1	3	1	1	1	2	2	2	2	2		1	1	1		1	6	1	2
		P	4_Mid-Surface	4.5	1	1						1		1							1	1
			5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N19	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N20	32	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N21	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
				Totals		111	22	22	42	42	42	42	42	33	1	4	4	2	4	36	10	11
Blanks A									1	1	1	1	1									

Table 2-3. Farfield Water Column Sampling Plan (3 Pages)

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	0.1	1	1	1
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F01	27	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F02	33	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F03	17	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F05	18	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F06	35	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F07	54	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F10	30	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	4	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F12	90	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	4	1	1								1	1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F13	25	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorus	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F14	20	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F15	39	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F16	60	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F17	78	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F18	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7	2	1	1	1	2	2	2	1	2							6		
			2_Mid-Bottom	2	1	1						1		1								
F19	81	A	3_Mid-Depth	7	2	1	1	1	2	2	2	2	2							6		
		+R	4_Mid-Surface	2	1	1						1		1								
			5_Surface	7	2	1	1	1	2	2	2	1	2		1					6		
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F22	80	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	18	3	1	1	1	2	2	2	1	2							6	1	1
		D	2_Mid-Bottom	8.5	1	1						1		1							1	2
F23	25	+R	3_Mid-Depth	24	3	1	1	1	2	2	2	2	2			1	1		1	6	1	1
		+P	4_Mid-Surface	7.5	1	1						1		1							1	1
			5_Surface	23	3	1	1	1	2	2	2	1	2		1	1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F24	20	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								

Farfield Water Column Sampling Plan

StationID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F26	56	D	3_Mid-Depth	15	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F27	108	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F28	33	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	2	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F29	66	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	2	1	1								1	1							
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
F32	30	Z	5_Surface												1							
			6_Net Tow															1				
F33	30	Z	5_Surface												1							
			6_Net Tow															1				
			1_Bottom	8.1	2	1	2	2	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
					otals	132	44	44	84	84	84	80	84	96	28	26	26	15	26	36	5	6
			Blanks B						1	1	1	1	1									
			Blanks C						1	1	1	1	1									
			Blanks D						1	1	1	1	1									

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the final HOM Program 2001 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Table 3-1 Method Detection Limits, Survey Data Tables 3-2 through 3-8). Each table provides summary data from one survey. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum) is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted to provide an efficient way of assessing the status of the regions during a particular survey. Maximum and minimum values are provided because of the need to assess extremes of pre-outfall conditions relative to criteria being developed for contingency planning purposes (MWRA, 2001).

Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit within a survey. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on precision of the specific data set. Detailed considerations for individual data sets are provided in the sections below.

3.1 Defined Geographic Areas

The primary partitioning of data is between the nearfield and farfield stations (Figures 1-1 and 1-2). Farfield data were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in Figure 1-2.

The data summary tables include data derived from all of the station data collected in each region. Average, maximum, and minimum values are reported from the cumulative horizontal and vertical dataset as described for each data type below.

3.2 Sensor Data

Six CTD profile parameters provided in the data summary tables include temperature, salinity, density (σ_t), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the sensor readings collected at five depths through the water column (defined as A-E). These depths were sampled on the upcast of the hydrographic profile. The five depth values, rather than the entire set of profile data, were selected to reduce the statistical weighting of deep-water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. The mid-depth sample (C) was typically located at the subsurface fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are available in the Water Column Monitoring CW/QAPP (Albro *et al.,* 2002), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-t (σ_t), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semi-annual period, density varied from 1020.1 to 1026.3, meaning σ_t varied from 20.1 to 26.3.

Fluorescence data were calibrated using concomitant extracted chlorophyll *a* data from discrete water samples collected at a subset of the stations (see CW/QAPP or Tables 2-1, 2-2, 2-3). The calibrated fluorescence sensor values were used for all discussions of chlorophyll in this report. The concentrations of phaeopigments are included in the summary data tables as part of the nutrient parameters.

In addition to DO concentration, the derived percent saturation was also provided. Percent saturation was calculated prior to averaging station visits from the potential saturation value of the water (a function of the physical properties of the water) and the calibrated DO concentration (see CW/QAPP).

Finally, the derived beam attenuation coefficient from the transmissometer ("transmittance") was provided on the summary tables. Beam attenuation is calculated from the natural logarithm of the ratio of light transmission relative to the initial light incidence, over the transmissometer path length, and is provided in units of m^{-1}.

3.3 Nutrients

Analytical results for dissolved and particulate nutrient concentrations were extracted from the HOM database, and include: ammonia (NH_4), nitrite (NO_2), nitrate + nitrite (NO_3+NO_2), phosphate (PO_4), silicate (SiO_4), biogenic silica (BSI), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PP), and urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. Dissolved inorganic nutrients (NH_4, NO_2, NO_3+NO_2, PO_4, and SiO_4) were measured from water samples collected from each of the five (A-E) depths during CTD casts. The dissolved organic and particulate constituents were measured from water samples collected from the surface (A), mid-depth (C), and bottom (E) sampling depths (see Tables 2-1, 2-2, and 2-3 for specific sampling depths and stations).

3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. Areal production, which is determined by integrating the measured productivity over the photic zone, and chlorophyll-specific areal production is included for the productivity stations (F23 representing the Harbor, and N04 and N18, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters α (gC[gChla]$^{-1}$h^{-1}[μEm^{-2}s^{-1}]$^{-1}$) and Pmax (gC[gChla]$^{-1}$h^{-1}) are also included. The productivity parameters are discussed in detail in Appendix A.

Respiration rates were averaged over the respiration stations (the same Harbor and nearfield stations as productivity, and additionally one offshore station [F19]), and over the three water column depths sampled (surface, mid- and bottom). The respiration samples were collected concurrently with the productivity samples. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al.,* 2002).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-μm Nitrex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-μm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al.,* 2002).

Final plankton values were derived from each station by first averaging analytical replicates, then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (Tables 3-2 through 3-8).

Results for total phytoplankton and centric diatoms reported in Tables 3-1 through 3-8 are restricted to whole water surface samples. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Temperature and chlorophyll *a* satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine and upwelling (Appendix I). U.S. Geological Service continuous temperature and salinity data were collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1). Hourly temperature and salinity data from the mid-depth (~13 m below surface) and near-bottom (1 m above bottom) are plotted in Figure 3-1. Chlorophyll *a* data (as measured by *in situ* fluorescence) from the MWRA Wetlab sensor mounted at mid-depth (~13 m below surface) on the nearfield USGS mooring are plotted in Figure 3-2.

The 13m temperature and salinity data were first collected during the May 24th deployment (new SeaCat CTD) and will be included in future semiannual reports. Data from the 10-meter above bottom (~20m depth) array (usually presented herein) were lost due to instrument failure.

Table 3-1. Method Detection Limits

Analysis	MDL
Dissolved ammonia (NH_4)	0.02 μM
Dissolved inorganic nitrate (NO_3)	0.01 μM
Dissolved inorganic nitrite (NO_2)	0.01 μM
Dissolved inorganic phosphorus (PO_4)	0.01 μM
Dissolved inorganic silicate (SIO_4)	0.02 μM
Dissolved organic carbon (DOC)	20 μM
Total dissolved nitrogen (TDN)	1.43 μM
Total dissolved phosphorus (TDP)	0.04 μM
Particulate carbon (POC)	5.27 μM
Particulate nitrogen (PON)	0.75 μM
Particulate phosphorus (PARTP)	0.04 μM
Biogenic silica (BIOSI)	0.32 μM
Urea	0.2 μM
Chlorophyll *a* and phaeophytin	0.036 μg L^{-1}
Total suspended solids (TSS)	0.1 mg L^{-1}

Table 3-2. Combined Farfield/Nearfield Survey WF011 (Feb 01) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	2.96	5.93	4.60	2.14	3.25	2.76	2.02	3.19	2.71
Salinity	PSU	32.2	33.2	32.6	31.8	32.2	32.1	31.9	32.4	32.2
Sigma _T		25.6	26.3	25.8	25.4	25.7	25.6	25.5	25.8	25.7
Beam Attenuation	m^{-1}	0.58	1.17	0.80	1.02	1.51	1.28	1.02	1.38	1.16
DO Concentration	mgL^{-1}	9.82	11.77	10.48	10.51	12.38	11.49	10.35	11.31	10.77
DO Saturation	PCT	61.9	108.5	93.7	96.2	111.8	105.3	95.1	103.2	98.6
Fluorescence	μgL^{-1}	0.63	8.78	3.48	1.49	11.26	6.30	0.23	3.62	1.82
Chlorophyll a	μgL^{-1}	0.77	3.74	1.81	5.58	10.42	7.38	0.91	3.54	2.02
Phaeopigment	μgL^{-1}	0.12	0.65	0.30	0.55	1.50	0.99	0.13	0.42	0.27
Nutrients										
NH4	µM	0.26	2.44	0.73	0.31	1.43	1.02	0.50	1.23	0.77
NO2	µM	0.02	0.16	0.12	0.15	0.18	0.17	0.14	0.23	0.18
NO2+NO3	µM	1.19	8.56	6.50	3.40	7.22	5.51	4.81	6.04	5.56
PO4	µM	0.47	1.08	0.77	0.65	0.88	0.78	0.51	0.79	0.67
SIO4	µM	0.50	6.45	4.15	0.34	2.16	1.50	1.37	4.99	2.45
BIOSI	µM	1.50	4.70	3.35	5.40	6.70	6.02	2.90	5.60	3.66
DOC	µM	112.7	215.1	145.6	115.8	459.3	189.9	120.6	180.1	141.7
PARTP	µM	0.06	0.24	0.13	0.34	0.47	0.41	0.18	0.23	0.20
POC	µM	8.58	24.70	14.51	29.40	42.50	37.62	16.20	20.00	18.16
PON	µM	1.54	4.19	2.60	4.61	7.21	6.12	2.46	3.34	2.93
TDN	µM	17.0	81.3	40.0	16.2	39.1	22.6	15.7	25.3	19.2
TDP	µM	0.81	1.05	0.97	0.77	0.96	0.87	0.71	0.93	0.82
TSS	mgL^{-1}	0.30	1.30	0.77	1.14	1.97	1.47	0.82	1.79	1.39
Urea	µM	0.10	0.32	0.17	0.10	0.57	0.22	0.10	0.63	0.40
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.237	0.549	0.386	1.326	1.608	1.479	0.336	0.460	0.386
Centric diatoms	10^6Cells L^{-1}	0.024	0.141	0.068	0.696	0.907	0.805	0.069	0.133	0.098
Alexandrium spp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0023	0.0113	0.0059	0.0092	0.0092	0.0092	0.0015	0.0058	0.0037

Total Zooplankton	Individuals m^{-3}	9,383	16,411	12,897	8,533	23,133	15,242	2,914	13,068	8,635

Table 3-2. Combined Farfield/Nearfield Survey WF011 (Feb 01) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	1.03	2.51	1.96	3.91	5.43	4.32	2.55	4.43	3.94
Salinity	PSU	31.1	31.9	31.6	32.4	32.8	32.5	32.0	32.5	32.3
Sigma _T		24.8	25.6	25.3	25.7	25.9	25.8	25.5	25.8	25.7
Beam Attenuation	m^{-1}	1.27	2.16	1.62	0.83	0.97	0.91	0.87	1.31	1.03
DO Concentration	mgL^{-1}	11.12	12.01	11.64	10.04	11.03	10.44	10.46	11.52	11.05
DO Saturation	PCT	99.8	108.4	104.2	94.9	105.1	99.7	99.9	109.0	104.5
Fluorescence	μgL^{-1}	0.95	1.26	1.06	1.07	5.14	3.06	1.00	5.72	3.52
Chlorophyll a	μgL^{-1}	0.85	1.51	1.16	1.19	3.72	2.75	0.45	6.92	3.86
Phaeopigment	μgL^{-1}	0.10	0.63	0.39	0.17	1.39	0.37	0.09	0.95	0.45
Nutrients										
NH4	μM	0.93	2.15	1.34	0.15	1.87	0.45	0.12	7.30	1.21
NO2	μM	0.02	0.28	0.13	0.13	0.20	0.15	0.13	0.20	0.16
NO2+NO3	μM	5.51	8.87	6.75	5.27	7.69	6.05	4.93	6.87	5.84
PO4	μM	0.48	1.46	0.78	0.63	0.84	0.74	0.56	0.90	0.70
SIO4	μM	3.66	8.13	5.23	1.16	6.51	2.85	1.59	7.32	2.47
BIOSI	μM	2.70	5.50	3.68	3.80	5.00	4.24	2.70	5.50	4.60
DOC	μM	148.1	201.1	164.1	113.8	228.2	155.6	107.7	196.2	135.9
PARTP	μM	0.18	0.32	0.25	0.11	0.19	0.16	0.15	0.29	0.21
POC	μM	13.80	38.80	20.38	8.58	19.90	15.40	12.20	90.00	21.65
PON	μM	2.09	4.01	2.95	1.59	3.24	2.56	2.04	4.55	3.24
TDN	μM	18.4	149.3	34.8	17.2	138.2	42.2	14.8	58.9	20.8
TDP	μM	0.77	0.98	0.86	0.88	1.00	0.93	0.19	1.03	0.88
TSS	mgL^{-1}	0.73	4.32	2.19	0.27	0.95	0.79	0.55	2.42	0.92
Urea	μM	0.38	1.14	0.68	0.10	1.39	0.77	0.10	0.76	0.38
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.027	0.042	0.033				0.075	0.164	0.131
Pmax	$mgCm^{-3}h^{-1}$	4.08	5.14	4.54				11.38	16.92	14.80
Areal Production	$mgCm^{-2}d^{-1}$			203.9				879.4	1,122.1	1,000.8
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$			8.9				6.0	8.9	7.5
Respiration	μMO_2h^{-1}	0.051	0.098	0.071	0.052	0.062	0.058	0.036	0.084	0.052
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.317	0.435	0.390	0.343	0.600	0.485	0.370	0.572	0.517
Centric diatoms	10^6Cells L^{-1}	0.057	0.095	0.076	0.113	0.187	0.147	0.126	0.200	0.167
Alexandrium spp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0005	0.0057	0.0021	0.0056	0.0157	0.0104	0.0111	0.0232	0.0191
Total Zooplankton	Individuals m^{-3}	4,885	6,504	5,520	17,462	21,234	19,348	14,888	28,403	21,112

Table 3-3. Combined Farfield/Nearfield Survey WF012 (Feb–Mar 01) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	3.28	4.59	4.00	2.12	3.12	2.65	2.43	3.43	2.97
Salinity	PSU	32.3	32.5	32.4	31.9	32.2	32.1	31.9	32.4	32.2
Sigma _T		25.6	25.8	25.7	25.5	25.6	25.6	25.5	25.7	25.6
Beam Attenuation	m^{-1}	0.66	0.86	0.73	0.87	1.01	0.93	0.66	0.85	0.78
DO Concentration	mgL^{-1}	10.48	11.07	10.77	11.21	12.47	11.85	10.93	11.88	11.22
DO Saturation	PCT	99.7	105.1	101.9	103.1	112.4	108.2	101.9	108.0	103.3
Fluorescence	µgL^{-1}	1.13	4.98	3.09	2.10	7.46	4.92	0.86	3.22	2.20
Chlorophyll a	µgL^{-1}	2.05	5.50	3.76	1.86	7.57	4.57	1.39	3.10	2.28
Phaeopigment	µgL^{-1}	0.38	1.09	0.73	0.43	1.22	0.79	0.23	0.55	0.35
Nutrients										
NH4	µM	0.43	1.18	0.76	0.16	0.79	0.47	0.32	1.19	0.76
NO2	µM	0.08	0.14	0.11	0.06	0.12	0.09	0.10	0.15	0.12
NO2+NO3	µM	3.34	5.66	4.44	0.19	2.00	1.01	2.33	3.67	3.19
PO4	µM	0.50	0.74	0.64	0.19	0.47	0.33	0.35	0.64	0.46
SIO4	µM	0.54	7.16	2.54	0.34	0.94	0.57	1.37	4.20	1.94
BIOSI	µM	0.16	3.80	2.56	2.10	2.70	2.42	1.40	1.70	1.61
DOC	µM	125.4	199.0	153.5	120.8	200.2	160.6	147.6	406.2	245.8
PARTP	µM	0.14	0.24	0.19	0.27	0.37	0.31	0.15	0.21	0.18
POC	µM	15.40	28.80	20.00	23.80	31.80	28.82	13.70	18.90	15.23
PON	µM	2.37	4.79	3.27	4.16	5.46	4.99	2.06	3.06	2.66
TDN	µM	12.6	17.1	14.7	11.0	14.3	12.8	11.7	20.3	15.3
TDP	µM	0.82	0.93	0.85	0.52	0.73	0.65	0.68	0.90	0.79
TSS	mgL^{-1}	0.34	0.86	0.60	0.08	0.99	0.68	0.13	0.82	0.51
Urea	µM	0.10	0.10	0.10	0.10	0.64	0.37	0.10	1.03	0.42
Productivity										
Alpha	mgCm^{-3}h^{-1}(µEm^{-2}s^{-1})$^{-1}$									
Pmax	mgCm^{-3}h^{-1}									
Areal Production	mgCm^{-2}d^{-1}									
Chlorophyll-Specific Depth-Averaged Production	mgC(mg Chla)$^{-1}$d^{-1}									
Respiration	µMO$_2$h^{-1}									
Plankton										
Total Phytoplankton	10^{6}Cells L^{-1}	0.395	0.609	0.483	0.182	1.024	0.656	0.217	0.494	0.340
Centric diatoms	10^{6}Cells L^{-1}	0.204	0.284	0.246	0.061	0.447	0.274	0.081	0.174	0.128
Alexandrium ssp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phaeocystis pouchetii	10^{6}Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Psuedo-nitzschia pungens	10^{6}Cells L^{-1}	0.0006	0.0031	0.0013	0.0033	0.0242	0.0131	0.0006	0.0012	0.0008
Total Zooplankton	Individuals m^{-3}	6,808	10,822	8,815	13,640	21,333	15,966	9,436	15,985	12,234

Table 3-3. Combined Farfield/Nearfield Survey WF012 (Feb–Mar 01) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	2.12	2.54	2.32	3.30	4.20	3.72	3.31	4.04	3.74
Salinity	PSU	30.9	32.0	31.6	32.4	32.5	32.4	32.3	32.5	32.4
Sigma _T		24.6	25.5	25.2	25.7	25.8	25.8	25.6	25.8	25.8
Beam Attenuation	m^{-1}	0.88	1.20	1.02	0.57	0.71	0.65	0.63	0.92	0.70
DO Concentration	mgL^{-1}	11.42	11.80	11.63	10.73	11.62	11.06	10.57	11.12	10.85
DO Saturation	PCT	103.8	106.3	105.0	101.4	108.2	104.0	100.0	104.9	102.1
Fluorescence	μgL^{-1}	2.55	3.68	3.16	1.27	2.97	2.26	0.52	3.82	2.05
Chlorophyll a	μgL^{-1}	1.93	2.93	2.60	1.71	3.10	2.43	1.56	3.68	2.39
Phaeopigment	μgL^{-1}	0.21	0.47	0.36	0.32	0.63	0.42	0.17	0.70	0.35
Nutrients										
NH4	μM	0.38	1.15	0.62	0.56	2.22	1.06	0.46	9.69	1.65
NO2	μM	0.11	0.19	0.15	0.08	0.21	0.11	0.04	0.20	0.11
NO2+NO3	μM	1.67	3.42	2.24	3.59	5.04	4.55	3.83	5.46	4.76
PO4	μM	0.22	0.46	0.35	0.53	0.77	0.66	0.60	1.02	0.70
SIO4	μM	1.57	7.49	3.19	0.56	4.74	1.68	1.36	6.99	2.20
BIOSI	μM	1.70	4.00	2.27	1.50	2.80	2.27	1.50	2.30	1.87
DOC	μM	134.1	249.0	190.2	143.5	408.7	216.3	135.1	452.6	194.6
PARTP	μM	0.19	0.32	0.25	0.13	0.17	0.14	0.11	0.23	0.15
POC	μM	15.70	28.50	21.51	12.50	19.80	15.49	10.00	20.00	14.23
PON	μM	3.17	4.44	3.67	1.91	3.41	2.70	1.84	3.56	2.36
TDN	μM	11.5	15.2	13.1	14.1	17.4	15.8	13.7	22.6	16.3
TDP	μM	0.53	0.70	0.60	0.82	1.00	0.91	0.82	1.08	0.91
TSS	mgL^{-1}	0.28	1.68	0.91	0.16	0.63	0.38	0.17	0.81	0.55
Urea	μM	0.10	1.03	0.54	0.10	0.25	0.18	0.10	0.31	0.17
Productivity										
Alpha	mgCm^{-3}h^{-1}(μEm^{-2}s^{-1})$^{-1}$	0.084	0.095	0.091				0.029	0.099	0.072
Pmax	mgCm^{-3}h^{-1}	8.86	11.50	10.15				5.71	8.14	6.88
Areal Production	mgCm^{-2}d^{-1}			999.5				1063.4	1494.1	1278.8
Chlorophyll-Specific Depth-Averaged Production	mgC(mg Chla)$^{-1}$d^{-1}			19.2				15.9	21.2	18.6
Respiration	μMO$_2$h^{-1}	0.044	0.090	0.070	0.011	0.041	0.030	0.031	0.059	0.044
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.276	0.399	0.339	0.272	0.361	0.316	0.256	0.439	0.348
Centric diatoms	10^6Cells L^{-1}	0.120	0.180	0.147	0.085	0.144	0.116	0.091	0.178	0.120
Alexandrium spp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	ND	0.0005	0.0020	0.0012	0.0006	0.0028	0.0019
Total Zooplankton	Individuals m^{-3}	1,967	9,445	5,966	7,818	23,479	15,649	10,655	13,399	12,056

Table 3-4. Nearfield Survey WN013 (Mar 01) Data Summary

Region		**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	3.65	4.33	3.87
Salinity	PSU	29.3	32.3	31.4
Sigma _T		23.2	25.7	24.9
Beam Attenuation	m^{-1}	0.71	2.01	1.04
DO Concentration	mgL^{-1}	9.88	10.55	10.30
DO Saturation	PCT	92.8	99.9	96.4
Fluorescence	μgL^{-1}	0.02	2.17	0.76
Chlorophyll a	μgL^{-1}	0.14	1.36	0.66
Phaeopigment	μgL^{-1}	0.15	1.14	0.34
Nutrients				
NH4	µM	0.76	6.07	2.38
NO2	µM	0.02	0.25	0.15
NO2+NO3	µM	5.93	7.98	6.81
PO4	µM	0.51	1.69	0.87
SIO4	µM	4.92	9.60	6.50
BIOSI	µM	2.05	3.88	2.88
DOC	µM	140.4	483.1	256.9
PARTP	µM	0.09	0.32	0.18
POC	µM	7.29	29.80	14.81
PON	µM	1.41	4.69	2.35
TDN	µM	21.6	79.3	35.3
TDP	µM	0.87	1.16	1.02
TSS	mgL^{-1}	0.40	2.31	1.13
Urea	µM	0.10	1.57	0.89
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.008	0.042	0.024
Pmax	$mgCm^{-3}h^{-1}$	1.32	3.98	2.55
Areal Production	$mgCm^{-2}d^{-1}$	306.9	659.5	483.2
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$	15.2	16.8	16.0
Respiration	μMO_2h^{-1}	0.011	0.059	0.031
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.366	0.493	0.444
Centric diatoms	10^6Cells L^{-1}	0.061	0.136	0.094
Alexandrium spp.	Cells L^{-1}	ND	ND	ND
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	0.003	0.003
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0005	0.0038	0.0021
Total Zooplankton	Individuals m^{-3}	16,152	22,656	19,404

Table 3-5. Combined Farfield/Nearfield Survey WF014 (Apr 01) Data Summary

Region		Farfield								
		Boundary			Cape Cod Bay			Coastal		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	3.60	4.69	4.07	4.18	5.71	4.86	3.85	4.86	4.17
Salinity	PSU	28.0	32.4	31.5	31.1	31.8	31.4	29.9	31.6	31.1
Sigma _T		22.2	25.7	25.0	24.6	25.2	24.9	23.6	25.1	24.6
Beam Attenuation	m^{-1}	0.63	1.44	0.90	0.67	1.34	1.02	0.82	1.64	1.10
DO Concentration	mgL^{-1}	9.63	11.74	10.65	9.58	10.76	10.33	10.35	11.40	10.87
DO Saturation	PCT	90.6	109.2	100.5	90.7	104.7	99.3	97.0	108.1	102.5
Fluorescence	μgL^{-1}	0.02	5.46	1.04	0.02	1.57	0.34	0.02	3.98	1.31
Chlorophyll a	μgL^{-1}	0.78	3.98	2.24	0.29	1.00	0.58	0.54	1.52	1.06
Phaeopigment	μgL^{-1}	0.02	2.73	0.93	0.02	0.52	0.28	0.15	0.62	0.40
Nutrients										
NH4	μM	0.17	3.53	1.33	1.02	2.32	1.62	1.25	3.27	1.98
NO2	μM	0.02	0.17	0.09	0.10	0.21	0.13	0.12	0.25	0.18
NO2+NO3	μM	0.13	5.10	3.29	4.05	5.42	4.95	3.05	5.85	4.86
PO4	μM	0.31	0.81	0.55	0.45	0.70	0.56	0.46	0.69	0.60
SIO4	μM	1.61	9.78	3.91	3.17	7.79	4.61	4.10	7.19	5.84
BIOSI	μM	1.17	2.83	2.00	1.17	2.38	1.73	2.37	3.85	2.99
DOC	μM	122.7	305.5	188.0	134.9	361.7	209.8	141.2	458.8	204.1
PARTP	μM	0.13	0.28	0.21	0.13	0.28	0.17	0.16	0.27	0.22
POC	μM	16.30	35.80	24.23	10.10	23.50	16.18	15.60	29.80	21.17
PON	μM	2.05	5.58	3.98	1.46	4.00	2.48	2.56	4.61	3.24
TDN	μM	11.1	17.0	14.0	15.7	21.9	17.9	16.3	24.9	19.0
TDP	μM	0.59	0.93	0.78	0.78	0.98	0.90	0.78	0.96	0.87
TSS	mgL^{-1}	0.44	1.22	0.80	0.47	1.33	0.82	0.84	1.46	1.20
Urea	μM	0.10	0.28	0.22	0.10	0.31	0.19	0.31	0.69	0.48
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.881	3.379	2.544	0.325	0.897	0.588	0.668	1.090	0.821
Centric diatoms	10^6Cells L^{-1}	0.034	0.039	0.037	0.009	0.200	0.061	0.061	0.121	0.085
Alexandrium spp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phaeocystis pouchetii	10^6Cells L^{-1}	0.608	3.130	2.236	0.046	0.065	0.056	0.245	0.589	0.608
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0029	0.0054	0.0039	0.0001	0.0001	0.0001	0.0007	0.0060	0.0032
Total Zooplankton	Individuals m^{-3}	25,600	32,588	29,094	25,640	41,485	31,738	13,663	19,321	16,745

Table 3-5. Combined Farfield/Nearfield Survey WF014 (Apr 01) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	3.90	5.27	4.52	3.70	4.83	3.97	3.71	5.14	4.00
Salinity	PSU	27.0	31.8	30.0	30.3	32.4	31.8	30.2	32.2	31.4
Sigma _T		21.3	25.3	23.7	24.0	25.7	25.2	23.9	25.6	24.9
Beam Attenuation	m^{-1}	1.49	2.10	1.72	0.57	1.15	0.74	0.60	1.52	0.85
DO Concentration	mgL^{-1}	10.19	11.02	10.57	9.56	11.82	10.59	10.07	11.77	10.95
DO Saturation	PCT	96.0	103.6	99.8	89.9	111.5	99.8	94.9	110.4	103.0
Fluorescence	μgL^{-1}	0.18	1.41	0.72	0.13	4.04	1.34	0.27	3.17	1.62
Chlorophyll a	μgL^{-1}	0.45	1.44	1.06	0.43	3.44	1.54	0.40	2.24	1.17
Phaeopigment	μgL^{-1}	0.39	0.75	0.59	0.19	2.30	0.65	0.15	1.35	0.50
Nutrients										
NH4	µM	1.32	3.46	2.26	0.52	2.94	1.52	0.66	7.73	1.93
NO2	µM	0.18	0.25	0.21	0.05	0.19	0.11	0.07	0.23	0.12
NO2+NO3	µM	4.67	11.73	7.02	1.27	5.35	3.93	2.99	6.42	4.61
PO4	µM	0.50	0.70	0.57	0.36	0.80	0.61	0.46	0.82	0.63
SIO4	µM	5.64	17.09	9.25	2.62	7.03	4.58	3.92	8.67	5.54
BIOSI	µM	3.15	5.57	4.41	1.26	4.14	1.99	1.01	3.37	2.29
DOC	µM	134.3	338.6	207.7	157.5	332.0	234.7	119.1	247.6	172.9
PARTP	µM	0.21	0.40	0.26	0.12	0.26	0.17	0.10	0.28	0.19
POC	µM	21.70	30.10	26.24	14.50	64.60	27.87	9.42	35.80	20.29
PON	µM	3.05	5.10	3.91	2.12	12.10	4.35	1.14	5.44	3.00
TDN	µM	17.36	30.11	22.88	12.58	18.10	15.01	13.63	22.98	16.84
TDP	µM	0.83	0.92	0.88	0.67	1.06	0.85	0.78	1.13	0.92
TSS	mgL^{-1}	1.62	3.71	2.80	0.17	0.92	0.66	0.04	1.51	0.73
Urea	µM	0.39	0.79	0.63	0.14	0.33	0.25	0.23	1.31	0.57
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.044	0.098	0.070				0.024	0.157	0.099
Pmax	$mgCm^{-3}h^{-1}$	5.74	11.31	8.09				2.95	9.59	6.65
Areal Production	$mgCm^{-2}d^{-1}$			689.2				1602.4	1875.7	1739.1
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$			23.7				50.8	65.8	58.3
Respiration	μMO_2h^{-1}	0.059	0.097	0.074	0.062	0.137	0.095	0.024	0.082	0.061
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.310	1.178	0.656	0.586	1.803	1.067	1.080	1.561	1.207
Centric diatoms	10^6Cells L^{-1}	0.026	0.137	0.073	0.023	0.076	0.046	0.046	0.102	0.075
Alexandrium spp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phaeocystis pouchetii	10^6Cells L^{-1}	0.061	0.620	0.254	0.193	1.462	0.685	0.641	1.126	0.807
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0003	0.0147	0.0036	0.0011	0.0019	0.0016	0.0010	0.0043	0.0022
Total Zooplankton	Individuals m^{-3}	4,212	13,220	8,684	9,606	18,226	13,916	12.223	15,990	14,421

Table 3-6. Nearfield Survey WN015 (Apr 01) Data Summary

Region		**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	3.92	8.48	5.91
Salinity	PSU	29.7	32.1	31.1
Sigma _T		23.2	25.5	24.5
Beam Attenuation	m^{-1}	0.50	1.13	0.73
DO Concentration	mgL^{-1}	9.53	11.51	10.41
DO Saturation	PCT	90.0	116.5	102.5
Fluorescence	μgL^{-1}	0.02	4.94	0.98
Chlorophyll a	μgL^{-1}	0.07	4.78	1.41
Phaeopigment	μgL^{-1}	0.06	1.88	0.53
Nutrients				
NH4	µM	0.23	20.62	2.63
NO2	µM	0.01	0.23	0.08
NO2+NO3	µM	0.05	5.21	1.95
PO4	µM	0.15	1.00	0.49
SIO4	µM	0.99	8.47	3.93
BIOSI	µM	0.67	4.97	1.98
DOC	µM	126.9	535.0	190.1
PARTP	µM	0.06	0.38	0.19
POC	µM	5.96	46.10	22.11
PON	µM	0.38	6.64	3.33
TDN	µM	8.9	23.0	14.5
TDP	µM	0.47	1.16	0.79
TSS	mgL^{-1}	0.22	1.45	0.73
Urea	µM	0.10	0.28	0.18
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.009	0.077	0.046
Pmax	$mgCm^{-3}h^{-1}$	0.32	6.91	4.15
Areal Production	$mgCm^{-2}d^{-1}$	1073.5	1108.4	1091.0
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$	53.1	54.3	53.7
Respiration	μMO_2h^{-1}	0.030	0.142	0.071
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.65	0.992	0.789
Centric diatoms	10^6Cells L^{-1}	0.066	0.168	0.124
Alexandrium spp.	Cells L^{-1}	ND	17.50	17.50
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0003	0.0026	0.0015
Total Zooplankton	Individuals m^{-3}	21,387	29,669	25,528

Table 3-7. Nearfield Survey WN016 (May 01) Data Summary

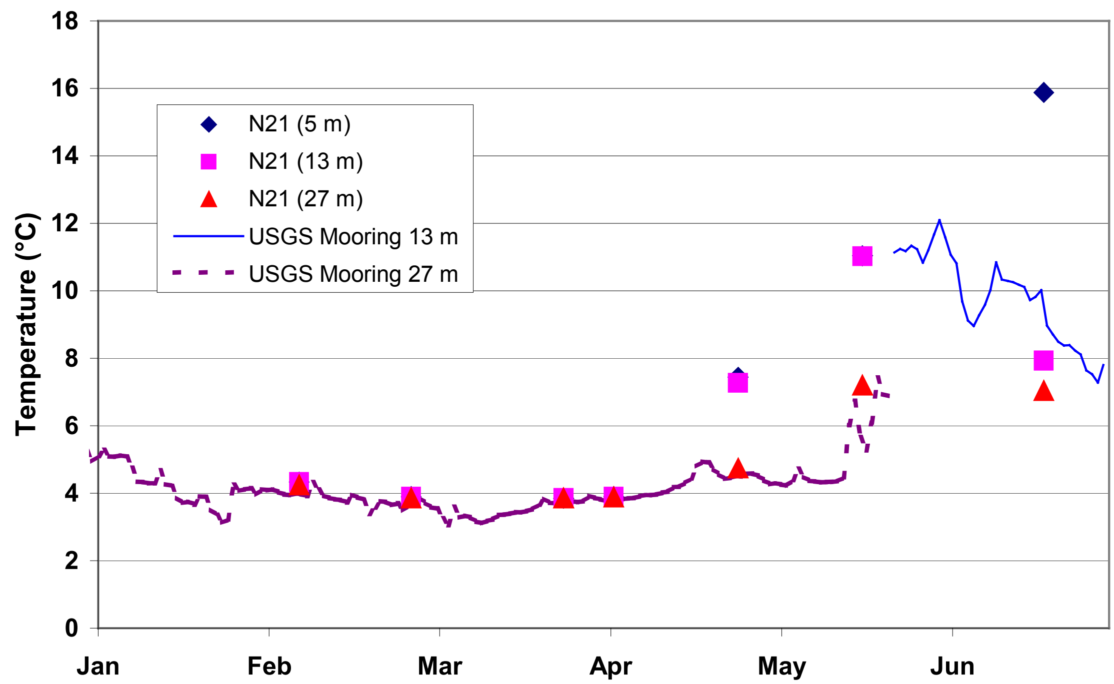
Region		**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**
In Situ				
Temperature	°C	4.17	11.31	9.31
Salinity	PSU	30.0	32.1	30.7
Sigma _T		22.9	25.5	23.7
Beam Attenuation	m^{-1}	0.45	1.61	0.79
DO Concentration	mgL^{-1}	9.27	10.35	9.72
DO Saturation	PCT	91.3	108.4	103.1
Fluorescence	μgL^{-1}	0.02	1.75	0.77
Chlorophyll a	μgL^{-1}	0.19	1.57	0.81
Phaeopigment	μgL^{-1}	0.15	1.05	0.45
Nutrients				
NH4	μM	0.07	19.54	1.44
NO2	μM	0.01	0.31	0.09
NO2+NO3	μM	0.01	4.38	0.78
PO4	μM	0.01	1.38	0.30
SIO4	μM	0.57	6.34	2.35
BIOSI	μM	0.40	5.60	2.09
DOC	μM	158.1	441.4	236.0
PARTP	μM	0.05	0.36	0.19
POC	μM	7.86	40.70	20.55
PON	μM	1.26	6.49	3.09
TDN	μM	8.0	17.2	12.4
TDP	μM	0.35	1.07	0.53
TSS	mgL^{-1}	0.05	1.77	0.67
Urea	μM	0.10	0.35	0.23
Productivity				
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.002	0.044	0.027
Pmax	$mgCm^{-3}h^{-1}$	0.30	4.39	2.47
Areal Production	$mgCm^{-2}d^{-1}$	490	561	526
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$	14.6	44.6	29.6
Respiration	μMO_2h^{-1}	0.029	0.094	0.076
Plankton				
Total Phytoplankton	10^6Cells L^{-1}	0.838	2.272	1.330
Centric diatoms	10^6Cells L^{-1}	0.130	1.532	0.656
Alexandrium spp.	Cells L^{-1}	ND	4.30	4.30
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	0.0003	0.0004	0.0004
Total Zooplankton	Individuals m^{-3}	32,027	54,651	43,339

Table 3-8. Combined Farfield/Nearfield Survey WF017 (Jun 01) Data Summary

		Farfield								
Region		**Boundary**			**Cape Cod Bay**			**Coastal**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	4.29	18.31	8.70	6.61	19.78	12.28	7.05	17.11	12.54
Salinity	PSU	29.8	32.1	31.4	30.4	31.5	30.9	30.3	31.4	30.8
Sigma _T		21.5	25.4	24.3	21.3	24.7	23.3	22.0	24.6	23.2
Beam Attenuation	m^{-1}	0.48	3.44	1.23	0.73	3.05	1.27	0.70	2.20	1.28
DO Concentration	mgL^{-1}	7.51	12.89	10.18	7.31	10.27	8.88	8.40	9.90	9.24
DO Saturation	PCT	91.8	125.4	106.3	73.3	117.2	100.6	91.5	116.8	105.2
Fluorescence	μgL^{-1}	0.02	4.16	0.64	0.02	2.05	0.85	0.02	3.99	1.76
Chlorophyll a	μgL^{-1}	0.07	2.06	0.75	0.14	1.27	0.64	0.24	3.58	1.45
Phaeopigment	μgL^{-1}	0.06	0.47	0.28	0.04	0.43	0.21	0.13	1.03	0.58
Nutrients										
NH4	µM	0.14	4.45	1.81	0.30	4.24	1.12	0.12	6.57	1.51
NO2	µM	0.01	0.44	0.17	0.01	0.26	0.07	0.01	0.30	0.14
NO2+NO3	µM	0.02	5.26	1.75	0.05	3.35	0.79	0.04	2.81	0.84
PO4	µM	0.14	0.89	0.52	0.18	1.04	0.47	0.13	0.74	0.41
SIO4	µM	0.22	8.10	3.22	1.77	12.99	4.53	0.63	10.71	2.98
BIOSI	µM	0.32	2.19	0.89	0.39	2.67	0.95	0.53	3.27	1.70
DOC	µM	176.6	641.2	375.3	196.1	344.3	258.3	167.5	393.5	275.2
PARTP	µM	0.05	0.30	0.17	0.15	0.27	0.21	0.16	0.44	0.28
POC	µM	11.50	48.60	34.10	21.30	54.10	31.27	25.60	42.50	33.97
PON	µM	4.89	8.57	7.01	5.29	10.30	7.32	5.27	9.07	7.32
TDN	µM	11.2	20.5	15.4	14.1	24.3	17.3	10.1	19.5	14.7
TDP	µM	0.37	0.92	0.65	0.30	1.16	0.64	0.34	0.83	0.63
TSS	mgL^{-1}	0.37	1.25	0.76	0.49	1.43	0.94	0.29	1.85	1.12
Urea	µM	0.24	0.39	0.35	0.10	0.61	0.28	0.10	0.39	0.30
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$									
Pmax	$mgCm^{-3}h^{-1}$									
Areal Production	$mgCm^{-2}d^{-1}$									
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$									
Respiration	μMO_2h^{-1}									
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	0.072	1.497	0.777	0.690	1.052	0.930	1.043	3.925	2.343
Centric diatoms	10^6Cells L^{-1}	0.021	0.612	0.252	0.027	0.079	0.051	0.035	2.385	0.934
Alexandrium spp.	Cells L^{-1}	ND	2.50	2.50	ND	ND	ND	ND	7.50	5.00
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	ND	0.0084	0.0084	0.0084	0.0009	0.0009	0.0009
Total Zooplankton	Individuals m^{-3}	14,239	21,818	18,029	23,187	32,580	27,884	21,153	28,474	25,806

Table 3-8. Combined Farfield/Nearfield Survey WF017 (Jun 01) Data Summary (continued)

		Farfield								
Region		**Harbor**			**Offshore**			**Nearfield**		
Parameter	**Unit**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
In Situ										
Temperature	°C	14.00	17.85	15.78	4.48	18.51	9.68	5.55	19.55	9.73
Salinity	PSU	27.9	30.5	29.6	30.4	32.0	31.3	30.3	31.7	31.2
Sigma _T		20.1	22.6	21.6	21.7	25.4	24.0	21.4	25.0	23.9
Beam Attenuation	m^{-1}	2.06	2.97	2.42	0.47	1.90	0.80	0.48	3.85	0.99
DO Concentration	mgL^{-1}	8.15	8.49	8.33	8.73	11.65	10.11	8.59	11.72	9.87
DO Saturation	PCT	96.2	107.0	100.8	88.6	120.7	108.2	90.7	122.6	105.9
Fluorescence	μgL^{-1}	2.09	4.83	3.48	0.02	6.45	1.05	0.02	7.89	1.12
Chlorophyll a	μgL^{-1}	1.66	4.94	3.31	0.08	4.36	1.62	0.02	4.57	1.52
Phaeopigment	μgL^{-1}	0.85	1.91	1.51	0.11	0.77	0.37	0.02	1.41	0.44
Nutrients										
NH4	µM	0.45	2.60	1.69	0.09	6.32	1.48	0.27	21.96	4.31
NO2	µM	0.10	0.41	0.24	0.01	0.39	0.12	0.01	0.52	0.15
NO2+NO3	µM	0.28	3.09	1.66	0.03	4.59	1.08	0.01	3.14	1.17
PO4	µM	0.31	0.58	0.46	0.04	0.91	0.42	0.10	1.27	0.58
SIO4	µM	3.08	10.29	6.44	0.31	9.20	2.58	0.39	10.34	3.86
BIOSI	µM	3.91	4.78	4.25	0.55	2.29	0.94	0.32	2.52	1.07
DOC	µM	214.2	760.1	406.0	216.3	715.3	374.1	178.2	670.8	289.0
PARTP	µM	0.44	0.57	0.51	0.12	0.45	0.23	0.07	0.50	0.26
POC	µM	32.80	49.90	41.66	10.80	65.60	30.24	11.40	62.10	32.10
PON	µM	7.79	10.10	8.58	4.66	10.00	7.01	4.04	11.00	7.40
TDN	µM	12.0	22.3	17.2	10.0	18.3	13.7	9.0	36.7	15.8
TDP	µM	0.59	0.87	0.76	0.33	1.06	0.60	0.35	1.45	0.69
TSS	mgL^{-1}	2.22	3.16	2.76	0.42	1.23	0.73	0.19	1.28	0.68
Urea	µM	0.31	0.83	0.45	0.10	0.61	0.35	0.10	0.54	0.32
Productivity										
Alpha	$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$	0.070	0.127	0.103				0.002	0.087	0.040
Pmax	$mgCm^{-3}h^{-1}$	11.77	22.51	16.50				0.33	7.43	4.11
Areal Production	$mgCm^{-2}d^{-1}$			1408.7				801.7	1336.2	1069.0
Chlorophyll-Specific Depth-Averaged Production	$mgC(mg\ Chla)^{-1}d^{-1}$			19.6				8.3	35.6	22.0
Respiration	μMO_2h^{-1}	0.121	0.166	0.146	0.068	0.217	0.120	0.041	0.406	0.186
Plankton										
Total Phytoplankton	10^6Cells L^{-1}	1.777	4.418	2.606	0.450	1.715	0.889	0.338	1.332	0.697
Centric diatoms	10^6Cells L^{-1}	0.061	1.723	0.562	0.032	0.205	0.107	0.014	0.114	0.077
Alexandrium spp.	Cells L^{-1}	ND	ND	ND	ND	ND	ND	7.50	35.00	24.17
Phaeocystis pouchetii	10^6Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Psuedo-nitzschia pungens	10^6Cells L^{-1}	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Zooplankton	Individuals m^{-3}	37,185	82,551	59,955	89,65	12,879	10,922	9,727	11,866	10,794



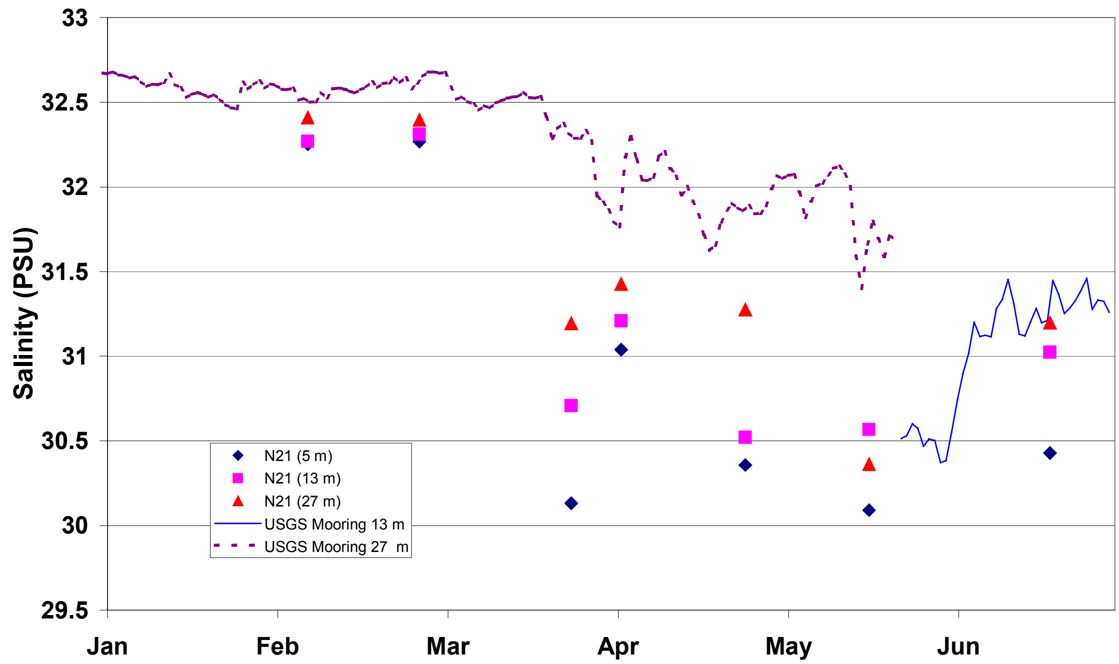


Figure 3-1. USGS Temperature and Salinity Mooring Data Compared with Station N21

(Note: 13m instrument first deployed May 2001 and data not yet available for May 2001 deployment of 20m and 27m instrument. The 20m instrument failed during Jan-May 2001 deployment.)

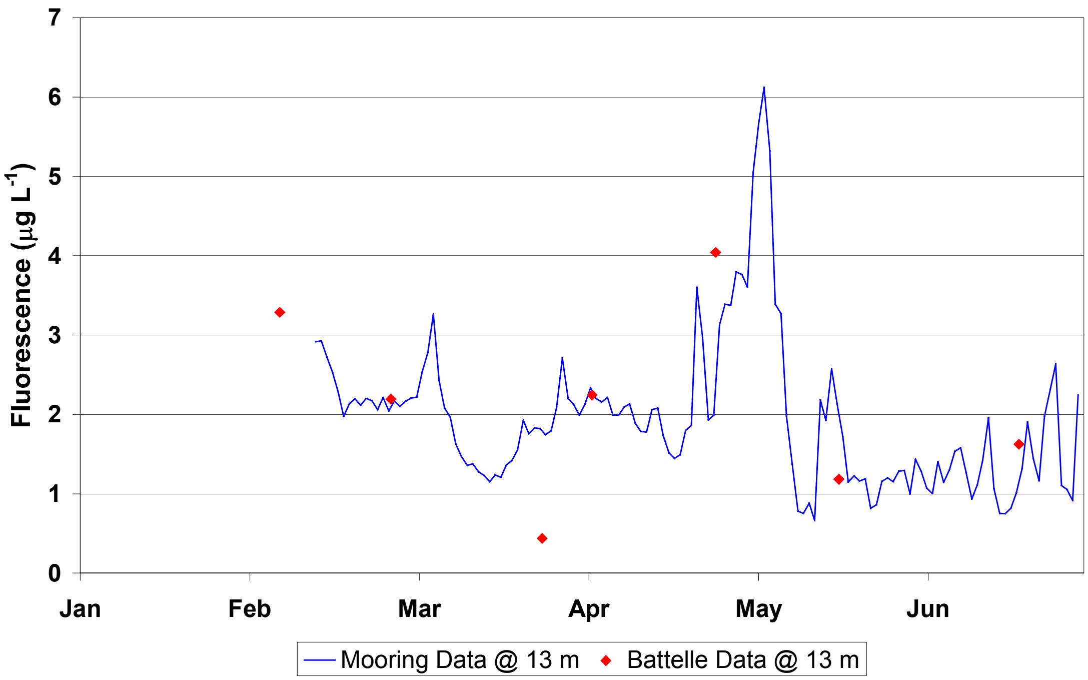


Figure 3-2. MWRA and Battelle *In Situ* Wetstar Fluorescence Data (MWRA Data Acquired at ~13 m on USGS Mooring and Battelle Data Acquired at 12.5 to 13.5 m at Station N21)

4.0 RESULTS OF WATER COLUMN MEASUREMENTS

Data presented in this section are organized by type of data and survey. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrients, chlorophyll *a*, and dissolved oxygen are discussed in Section 4.2. Finally a summary of the major results of water column measurements (excepting biological measurements) is provided in Section 4.4.

Four of the nine surveys conducted during the semi-annual period were combined farfield/nearfield surveys. The first two combined surveys in early February (WF011) and late February/early March (WF012) were conducted during winter well-mixed conditions. The water column had begun to stratify throughout Massachusetts Bay by the April combined survey (WF014), but remained well mixed in Cape Cod Bay. Stratification in Massachusetts Bay in April was driven by the salinity gradient between surface and bottom waters due to March/April runoff. The last combined survey (WF017) was conducted in June and a strong density gradient was observed at all stations in Massachusetts and Cape Cod Bays.

The variation of regional surface water properties is presented using contour plots of surface water parameters derived from the surface (A) water sample. Classifying data by regions allows comparison of the horizontal distribution of water mass properties over the farfield area. The vertical distribution of water column parameters is presented in the following sections along three farfield transects (Boston-Nearfield, Cohassett and Marshfield) in the survey area and one transect across the nearfield area (Figure 1-3). Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys allowing better temporal resolution of the changes in water column parameters and the onset of stratification. In addition to the nearfield vertical transect (Figure 1-3), vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set the surface contour maps, vertical transect plots and parameter scatter plots is provided in Appendices B, C and D, respectively.

4.1 Physical Characteristics

4.1.1 Temperature\Salinity\Density

The timing of the annual setup of vertical stratification in the water column is an important determinant of water quality, primarily because of the trend towards continuously decreasing dissolved oxygen in bottom water during the summer and early fall. The pycnocline, defined as a narrow water depth interval over which density increases rapidly, is caused by a combination of freshwater input during spring runoff and warming of surface water in the summer. Above the pycnocline the surface water is well mixed, and below the pycnocline density increases more gradually. For the purposes of this report, the water column is considered stratified when the difference between surface and bottom water density is greater than 1.0 sigma-t units (σ_t). Using this definition, stratification was developing in the nearfield in late March (WN013; Figure 4-1). The Broad Sound station N01 remained well mixed in March. The density profiles plotted over the February to June 2001 period suggest that although the pycnocline may have been developing in the nearfield in March and April, strong stratified conditions were not established across the entire nearfield until late May (Figure 4-2).

4.1.1.1 Horizontal Distribution

In early February (WF011), surface water temperatures were cold (1-4°C) across most of Massachusetts and Cape Cod Bays with slightly warmer water observed further offshore in Stellwagen Basin and on the Bank (4-6°C; Figure 4-3). The surface water temperatures ranged from 1.03°C at station F31 in Boston Harbor to 5.93°C at boundary station F27. Cooler waters were observed in Boston Harbor, coastal waters, and Cape Cod Bay and there was a clear inshore to offshore increase in temperatures. Surface water salinity also exhibited an inshore to offshore increase during WF011 (Figure 4-4). Lower salinity waters (<32 PSU) were observed in Boston Harbor and southern Cape Cod Bay, while the higher salinities were at boundary stations F27 and F28. Surface water temperatures showed little change by the end of February (WF012). Surface water temperatures ranged from 2.12°C at harbor station F23 to 4.59°C at boundary station F28. Cooler waters (< 3°C) continued to be present in Boston Harbor, coastal waters, and Cape Cod Bay. The distribution of minimum and maximum surface temperatures followed the general trend of increasing temperatures from south to north and inshore to offshore waters. A similar inshore to offshore pattern was observed for surface salinity data with lower surface salinity (<32 PSU) being observed in Boston Harbor and southern Cape Cod Bay and the higher salinity (>32.4 PSU) at most eastern nearfield, offshore, and boundary stations.

By early April (WF014), the range of surface water temperature had only increased a few degrees (4.7°C ± 1°C), but the shallow waters in Cape Cod Bay, Boston Harbor, and along coastal areas had become warmer creating a decreasing temperature gradient from inshore to offshore (Figure 4-5). In early April, the highest surface temperature was observed at Cape Cod station F03 (5.71°C) and the lowest at nearfield station N01 (3.74°C). The cooler temperatures (<4°C) were restricted to stations F23, N01 and N02, which were the first three stations sampled during the first day of the survey (April 4). Excepting these cool April 4th temperatures and the warmer surface waters in Boston Harbor and Cape Cod Bay, surface temperatures throughout the rest of Massachusetts Bay were relatively uniform (4-5°C). Surface salinity values had decreased to <30 PSU in the harbor and at station F26 off of Cape Ann and generally increased from inshore to offshore and from north to south (Figure 4-6). The lowest surface salinity was at station F30 (27.02 PSU) in Boston Harbor and the maximum at station F29 (31.89 PSU) off of Provincetown. The low surface salinity at station F26 is indicative of the spring freshet of lower salinity surface waters from the Gulf of Maine and rivers to the north. Flow in the Merrimack River was relatively low until mid-March, increasing sharply in late March reaching flows of 25,000-30,000 cfs (Figure 4-7), which likely contributed to the low surface salinity off of Cape Ann and into northern Massachusetts Bay. The Charles River followed a similar pattern with relatively low flow until mid-March and reached maximum flows (1,500-2,000 cfs) in late March and early April that led to low salinity in Boston Harbor. Precipitation measured at Boston's Logan airport was correlated to the river flow data as there were two large precipitation events with >2 in/d of rain in the mid to late March time frame, which combined with the seasonal melting of the snow pack led to increased riverine flows.

By June (WF017), surface water temperature had increased substantially across the bays ranging from a low of 11.76°C at station F26 to a maximum of 19.78°C in Cape Cod Bay at station F01 (Figure 4-8). Surface water temperatures were generally warmer to the south in Cape Cod Bay, southern Massachusetts Bay, and extending into the southeastern nearfield area. There was a high degree of variability in surface temperature in the nearfield ranging from a low of 13.01°C at station N13 to a high of 19.55°C at station N06. It is unclear what may have influenced the spatial variability in the nearfield. Certainly some of the variability is due to diurnal heating, but the timing of sampling suggests there were real spatial differences across the relatively small nearfield area. Surface water salinity ranged from 27.90 PSU at harbor station F30 to 30.87 PSU at boundary station F26 and was generally lower than measured in April. The June surface salinity pattern was similar to that seen in April, in that lower salinity surface waters were observed in Boston Harbor. It differed, however, in that higher salinity water was found off Cape Ann (Figure 4-9). There was a substantial rainfall event (1.7 inches on June 17 at Logan Airport) with concomitant increase in Charles River flow (Figure 4-7) that contributed to the low salinity in Boston Harbor. There was no appreciable increase in Merrimack River flow associated with this rainfall event (possibly rainfall concentrated to the Boston area and further south) so the lack of a salinity signal from this event at station F26 is not surprising. Note that a relatively low surface salinity value was observed at station F27, which is about 10 km further offshore from station F26. This area is often influenced by the same coastal currents and may reflect offshore passage of water influenced by the Merrimack River.

The changes that were observed in surface temperatures and salinity from February to April to June are indicative of the onset of seasonal stratification. The temperature-salinity (T-S) plots show a clear change in the relationship between these two parameters from early February to late June (Figures 4-10 and 4-11). In early February, the trend within each of the regions was that increasing temperatures were concurrent with increasing salinity. The surface waters were generally cooler and less saline than bottom waters and thus the density gradient was not significant. By late February/early March, this trend was less pronounced as surface and shallow waters warmed. The April survey occurred during a transition period. There was relatively little difference in temperature over the water column, but there was a wide range of salinity. By June, seasonal stratified conditions had been established with a warmer, less saline surface layer and cooler, more saline bottom waters. These patterns have been consistently observed over the baseline monitoring period.

4.1.1.2 Vertical Distribution

Farfield. As suggested previously, the density gradient ($\Delta\sigma_t$), representing the difference between the bottom and surface water σ_t, can be used as a relative indicator of a mixed or vertically stratified water column. Surface and bottom water density decreased over the course of this period throughout the farfield area (Figure 4-12). The water column was well mixed in each of the areas during the first two surveys (WF011 and WF012). During the April survey (WF014), stratified conditions ($\Delta\sigma_t \geq 1.0$) were observed at the harbor, offshore, and boundary stations. The development of stratification at these stations was driven by a substantial decrease in surface salinity (Figure 4-13). At coastal and Cape Cod Bay stations, density and salinity decreased from early March to April, but to similar degrees in both surface and bottom waters resulting in weaker April stratification. Surface and bottom water temperatures remained relatively unchanged during the first three combined surveys (Figure 4-14). By June (WF017), surface water temperatures had increased by >10°C throughout the bays. Bottom water temperatures increased by ~8°C in the harbor, ~4°C in coastal and Cape Cod Bay waters, and by 1-2°C in the offshore and boundary areas. There continued to be a relatively large salinity gradient (~1 PSU) in June. This combined with the increase in surface temperatures led to strongly stratified ($\Delta\sigma_t \sim 3$) conditions in Cape Cod Bay and offshore and boundary areas of Massachusetts Bay. Boston Harbor and coastal waters were less stratified ($\Delta\sigma_t \sim 1.5$).

The seasonal establishment of stratified conditions was also clearly illustrated in the vertical contour plots of sigma-T, salinity, and temperature (Appendix C). In February, there was little variation in these parameters over the water column, though as shown in the plot of σ_t along the Boston-Nearfield transect during WF012, the harbor exhibited slightly lower density water than the Massachusetts Bay stations (Figure 4-15a). This was due to slightly lower harbor salinity and increasing temperature from inshore to offshore (Figures 4-15b and 15c). In April (WF014), the physical characteristics of the water column suggested that the water column was becoming stratified across each of the transects, except in the nearfield where it appears that the input of freshwater from the outfall led to a decrease in bottom water density at station N21 compared to nearby nearfield stations N20 and N16 (Figure 4-16a). The ensuing mixing of the effluent and bottom waters into the surface waters resulted in higher density water being observed in surface waters of the nearfield versus inshore coastal/harbor stations and offshore stations. The effluent signal was also observed in the salinity and slightly in the temperature data (Figures 4-16b and 4-16c). The density gradients (vertical and horizontal) were driven by relatively large gradients in salinity as the water column remained relatively cool across the bays. The discharge at the outfall appears to delay the onset of stratified conditions in the nearfield. This will be addressed in more detail in the next section focused on the higher resolution nearfield surveys.

By June (WF017), a strong pycnocline had developed throughout the region (Figure 4-17). The onset of stratification in the spring is usually related to a freshening of the surface waters and then as the surface temperatures increase the density gradient or degree of stratification increases. This was once again the case in the spring of 2001. Stratified conditions in April were the result of spring rains and runoff. In June, salinity was still a factor as the June 17th rain event led to low salinity water in Boston Harbor and offshore surface waters (Figure 4-17b). Also in June, the large temperature gradient between surface and bottom waters was a contributing factor to the strong density gradient observed (Figure 4-17c). There was no clear signal associated with the outfall discharge during the June survey. A complete set of farfield transect plots of physical water properties is provided in Appendix C.

Nearfield. The onset of stratification can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and thus provide a more detailed picture of the physical characteristics of the water column. As illustrated in Figures 4-1 and 4-2, stratification was developing in the eastern nearfield in late March (WN013). Due to instrument problems and time constraints, density and salinity data are not available for most of the western half of the nearfield so it is unclear how stratification was progressing in those waters. The data from station N01 in Broad Sound suggest that the western nearfield remained well mixed in March (see Figure 4-1). The density profiles plotted over the February to June 2001 period suggest that although the pycnocline may have been developing in the nearfield in March and April, strong stratified conditions were not established at these nearfield stations until May (see Figure 4-2). These plots of the density profiles over time also indicate that there was some sort of mixing event in early April at station N21. The transect plots from WF014 suggest that this event was limited to the nearfield and may have been related to increased flow from the outfall discharge as a result of the March 30th rainfall (see Figure 4-7). By late April (WN015), the water column had become stratified across all of the nearfield area, but it was not until June that a strong density gradient ($\Delta\sigma_t > 2$) was established across the nearfield area. The physical characteristics that led to the establishment of stratified conditions are detailed below.

The gradient between surface and bottom water salinity followed a similar pattern to that of density – no gradient in February to early March, a gradient of ~1 PSU in the eastern nearfield in late March, and by early April there was a gradient of ~1 PSU across most of the nearfield area (Figure 4-18). The salinity gradient continued to increase at the outer nearfield stations reaching a maximum of ~3 PSU in June. The input of freshwater from late March rain events and runoff led to the establishment of the salinity gradient (and onset of stratification) in the nearfield and the large salinity gradient in June corresponded to the substantial rainfall on June 17th.

The nearfield water column was uniform with respect to temperature during the first four surveys of 2001 and there was very little change in nearfield temperatures over this period (Figure 4-19). It was not until late April (WN015) that surface temperatures began to increase. During this survey, there was ~4°C gradient between the surface and bottom waters (8°C versus 4°C, respectively) across the nearfield. By mid-May (WN016), surface water temperatures had increased to ~11°C throughout the nearfield, but the bottom water temperatures were not consistent. At the inshore nearfield stations N10 and N11, there was a large increase in bottom water temperatures from 5° to 10°C. This was likely due to the influence of tidal mixing. At Broad Sound station N01, bottom water temperature had increased to about 6.5°C, while at the offshore nearfield stations bottom water temperatures were ~5°C. By June (WF017), surface temperatures had increased to 15-18°C and bottom water temperatures ranged between 6-7°C, resulting in a strong gradient of 8°C at the inshore stations and an even stronger gradient of ~12°C at the deeper offshore stations. The increased temperature gradient between surface and bottom waters resulted in a stronger density gradient in June.

Higher temporal resolution salinity and temperature data are provided by USGS and presented in Figure 3-1. These mooring data are presented along with corresponding and surface data from station N21. The USGS mooring is located just to the south (1 km) of station N21 and the outfall. Unfortunately, the 20-m Seacat CTD did not function properly on the January to May deployment, but the addition of another Seacat CTD in conjunction with the MWRA WetStar fluorometer at ~13m does provide supplemental data for the late May to June period (May to June CTD data from 20 and 27m is not available at this time and will be included in 2001 annual water column report). Bottom water salinity remained relatively constant at 32.5 PSU from January to mid-March and then began to decrease. A similar, though more pronounced pattern was observed at station N21. The magnitude of bottom water variations at the mooring and station N21 were similar in April and May even though station N21 values remained ~1 PSU lower. By June, the mid-depth salinities were increasing and similar at both locations. Bottom water temperature at the USGS mooring and station N21 remained at 4°C from January to mid-May and the available data were comparable from the two sources for the entire period. The differences in bottom water salinity between the mooring and profile measurements at station N21 in April and May were likely due to the input of freshwater from the outfall.

4.1.2 Transmissometer Results

Water column beam attenuation was measured along with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient (m^{-1}) is indicative of particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) or suspended sediments. Beam attenuation data are often evaluated in conjunction with fluorescence data to ascertain source of the particulate materials (phytoplankton versus detritus or suspended sediments).

During early February survey (WF011), surface water beam attenuation ranged from 0.58 to 2.15 m^{-1} (Figure 4-20). The maximum value was measured in Boston Harbor at station F31 and the lowest value at boundary station F27. Elevated values were also observed in Cape Cod Bay, which corresponded to elevated chlorophyll concentrations (see Figure 4-37) and phytoplankton abundance associated with the winter/spring bloom occurring in those waters. Beam attenuation values were ~1 m^{-1} in the nearfield and coastal waters and lower offshore in Massachusetts Bay. The slightly elevated values in the nearfield corresponded with elevated chlorophyll concentrations, though neither was as high as those observed in Cape Cod Bay. By late February, beam attenuation values had decreased to 0.57 to 1.20 m^{-1}, but the general pattern of elevated values in the harbor and Cape Cod Bay and a decrease from inshore to offshore continued.

In early April (WF014), beam attenuation had increased in the harbor, coastal, western nearfield, and boundary waters off Cape Ann and ranged from a low of 0.64 m^{-1} at station F29 off Provincetown to 1.85 m^{-1} at station F31 in Boston Harbor (Figure 4-21). The elevated beam attenuation values observed at stations F26 and F27 were concomitant with a minor *Phaeocystis* bloom (see Sections 4.2.2 and 5.3). Otherwise, beam attenuation values tended to decrease with distance from the harbor. During the June survey (WF017), beam attenuation in the surface water ranged from 0.73 to 2.96 m^{-1} exhibiting a similar decrease in values from inshore to offshore stations (Figure 4-22). The usually high Boston Harbor and coastal water beam attenuation signal was higher still due to an increase in phytoplankton abundance in these waters (see Figure 5-21). The June surface water beam attenuation signal was also correlated with chlorophyll concentrations (see Appendix B).

The clear inshore to offshore horizontal gradient of decreasing beam attenuation away from Boston Harbor and the effect of the April *Phaeocystis* bloom can also be seen along the Boston-Nearfield transect (Figure 4-23). In February (WF011), elevated beam attenuation values were observed at harbor station F23 and coastal station F24 and decreased progressively with distance from shore. This same pattern was observed in late February (WF012). In April, the harbor signal was still seen, but the highest beam attenuation values were associated with the winter/spring *Phaeocystis* bloom that was most pronounced at boundary station F27. The elevated *Phaeocystis* abundances that were observed at this station and station F26 both off of Cape Ann were not found anywhere else in Massachusetts or Cape Cod Bays. This may have been an artifact of survey timing or the influence of prevailing winds/currents. The importance of the interaction of the Gulf of Maine Coast Current and prevailing winds to the transport of *Alexandrium tamarense* has been well documented (Anderson, 1997). The currents and winds may also play a role in the transport of *Phaeocystis*, which forms floating colonies, into the bays. Beam attenuation was lower at station N21 compared to surrounding waters. The low beam attenuation is correlated with similar differences in temperature and salinity associated with the rising /mixing effluent plume. By June (WF017), the strong harbor, coastal, and western nearfield signal dominated the inshore to offshore trends in beam attenuation along the Boston-Nearfield transect and were correlated with elevated chlorophyll concentrations.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were analyzed using surface water contour maps (Appendix B) and vertical contours from select transects (Appendix C) using the nutrient data to illustrate the spatial variability of these parameters. In addition, x/y plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships (Appendix D) were examined.

The nutrient data for February to June 2001 generally followed the typical progress of seasonal events in the Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring 'diatom bloom' reduced nutrient concentrations in Cape Cod Bay surface waters in February. Massachusetts Bay surface water nutrient concentrations decreased from early February through April, but did not reach depleted levels until June. In the nearfield, nutrient levels decreased in the surface waters following establishment of stratification. Nutrient concentrations in the surface waters were depleted throughout much of the region by late April. With the transfer of effluent discharge from the harbor outfall to Massachusetts Bay outfall, the harbor signal of elevated nutrient concentrations (especially ammonium) extending into the western nearfield that had been observed throughout the baseline period was not as intense. In 2001, elevated concentrations of NO_3 and SiO_4 continued to be observed at the inner harbor station F30, but maximum surface NH_4 and PO_4

concentrations were almost always found in the nearfield (usually at station N21). The effluent nutrient signal was clearly evident in the nearfield.

4.2.1.1 Horizontal Distribution

During this semi-annual period, the highest nutrient concentrations were consistently measured at the harbor, harbor-influenced coastal, and nearfield stations. Dissolved inorganic nutrients were generally highest in surface waters during the first survey (WF011). As observed during the fall of 2000, nearfield ammonium concentrations were consistently elevated with respect to farfield stations and compared to previous baseline monitoring years. Nutrient concentrations were lower in Cape Cod Bay than in Massachusetts Bay during the first two farfield surveys due to the winter/spring diatom bloom that occurred in Cape Cod Bay in February. By April (WF014), nutrient concentrations had increased in Cape Cod Bay and had decreased slightly in Massachusetts Bay. By June (WF017), nutrients were generally depleted in the surface waters throughout the bays, except for stations in Boston Harbor and the nearfield.

In early February (WF011), the highest nutrient values were found in Boston Harbor [phosphate (PO_4) = 1.46 µM at station F23 and silicate (SiO_4) = 6.6 µM at station F30], the nearfield [ammonium (NH_4) = 7.30 µM at station N21], and along the boundary [nitrate (NO_3) = 8.49 µM at station F27]. The lowest concentrations were observed in Cape Cod Bay at station F02 (SiO_4 = 0.47 µM), at boundary station F29 off Provincetown (PO_4 = 0.47 µM and NO_3 = 1.13 µM), and at nearfield station N05 (NH_4 = 0.12 µM). Generally there were elevated concentrations of NH_4 and PO_4 in the harbor and nearfield and elevated concentrations of NO_3 and SiO_4 in the harbor and the northeastern Massachusetts Bay stations. Slightly elevated NO_3 concentrations were also observed in nearfield surface waters (Figure 4-24). Silicate concentrations were slightly lower in the nearfield in comparison to stations further inshore and offshore. Elevated fluorescence and production (see Figures 5-4 and 5-5) in the nearfield surface waters suggests that nutrient uptake by diatoms decreased the nearfield SiO_4 concentrations. Nitrate concentrations remained elevated in those parts of the nearfield where NH_4 was plentiful due to preferential uptake of the reduced form of nitrogen (see Appendix B for plots). Nutrient concentrations were lower in Cape Cod Bay than in Massachusetts Bay due to the winter/spring diatom bloom that was evident in both the phytoplankton abundance and chlorophyll concentration data.

By late February/early March (WF012), nutrient concentrations in surface waters had decreased throughout the bays except for NH_4 and PO_4 in the nearfield (Figure 4-25). In Cape Cod Bay, nutrients had become depleted. The highest nutrient concentrations were in the nearfield at station N21 (NH4 = 9.69 µM and PO_4 = 1.02 µM) and at boundary stations F26 and F28 (SiO_4 = 6.75 µM and NO_3 = 5.46 µM, respectively). The lowest concentrations were in Cape Cod Bay at stations F01 (NO_3 = 0.24 µM), F02 (SiO_4 = 0.49 µM), and F03 (NH_4 = 0.16 µM and PO_4 = 0.22 µM). Ammonium concentrations continued to be very good tracer of the effluent plume. The low nutrient concentrations at Cape Cod Bay stations coincided with elevated chlorophyll concentrations and phytoplankton abundance (centric diatoms dominant) suggesting a continuation of the winter/spring bloom of centric diatoms observed in early February. Silicate concentrations were relatively low in late February/early March in the nearfield and southern Massachusetts Bay. This suggests uptake by diatoms, but concomitant chlorophyll and phytoplankton data do not support any increase in diatoms in these waters. The lower concentrations of NO_3 and SiO_4, however, suggest that there was an increase in utilization between early and late February.

By April (WF014), nutrient concentrations had increased over much of Massachusetts and Cape Cod Bays. The highest nutrient concentrations were still found in the nearfield (PO_4 = 0.82 µM, and

NH_4 = 7.73 µM at station N21) and Boston Harbor (NO_3 = 11.48 µM and SiO_4 = 17.09 µM at station F30). The high surface concentrations of NO_3 and SiO_4 at station F30 were caused by increased runoff and the corresponding increase in flow from the Charles and other tributaries to the inner harbor. Surface SiO_4 was also high (9.78 µM) at boundary station F26 off of Cape Ann due to the spring freshet. Nitrate concentrations remained relatively high in harbor, coastal, nearfield, and southern Massachusetts Bay and had increased from the late February depleted levels in Cape Cod Bay (Figure 4-26). Low surface water NO_3, PO_4, and NH_4 concentrations were observed in northeastern Massachusetts Bay (see Figure 4-26 for NO_3). Although these low concentrations were not coincident with elevated chlorophyll concentrations, high abundances of *Phaeocystis* (1-3 million cells L^{-1}) were found in the surface and mid-depth waters at stations F26, F27, and F22. The high abundance of *Phaeocystis* at these stations and its dominance throughout Massachusetts Bay (albeit at lower abundance) likely led to the increase in SiO_4 concentrations from the late February survey when diatoms were dominant. Ammonium concentrations continued to be elevated in the nearfield area surface waters.

In June (WF017), the highest surface concentrations were once again found in the nearfield (PO_4 = 0.59 µM at station N12 and NH_4 = 5.12 µM at station N14) and Boston Harbor (NO_3 = 2.75 µM and SiO_4 = 9.48 µM at station F23). Nutrient concentrations outside the harbor, near-harbor coastal, and nearfield stations had decreased to relatively low levels and there was a relatively strong gradient of decreasing concentrations away from these waters (Figure 4-27). The elevated nutrient concentrations in Boston Harbor, coastal and western nearfield waters were coincident with elevated chlorophyll concentrations. Low nutrient and chlorophyll concentrations were found throughout the rest of Massachusetts and Cape Cod Bays. This is typical of stratified summer conditions. Surface NH_4 concentrations remained elevated in the nearfield even though the water column was stratified. The rain event of June 17th likely led to an increase in flow from the outfall that may have led to a localized breakdown in stratification bringing the effluent plume and NH_4 to the surface. This was not readily apparent in the salinity data and will be evaluated in more detail in the 2001 annual report.

The usefulness of NH_4 as a tracer of the effluent plume has been shown for previous monitoring periods (Libby *et al*., 2001). Although it is not a conservative tracer due to biological utilization, NH_4 does provide a natural tracer of the effluent plume in the nearfield area especially in low light conditions where biological activity is minimal (i.e. below the pycnocline during stratified conditions and during the winter). In February, the effluent plume NH_4 signal was clearly observed over the entire water column in the nearfield with the highest concentrations in the surface waters (Figure 4-28a: WF012). This pattern continued to be observed in the nearfield in March and early April when the water column was beginning to stratify (Figure 4-28b). Increased flow at the outfall due to late March rain events may have weakened stratification in the nearfield and resulted in the surface expression of the NH_4 plume. By late April and May, the distribution of NH_4 concentrations suggests that the plume was trapped below the pycnocline (Figure 4-29a). In June, the effluent plume NH4 signal was once again observed in the nearfield surface waters (Figure 4-29b). Once again it appears that a rain event (>1.5 in on June 17th) may have led to increased flow from the outfall and a destabilization of the water column with NH_4 reaching the surface waters. This will be evaluated in more detail in the 2001 annual report. Ammonium in the water column has proven to be an excellent tracer of the effluent plume in the nearfield now that the outfall is online.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). During the first two surveys (WF011 and WF012), the transect contours indicated that the water column was generally replete with nutrients. The main deviation from this pattern was the surprisingly low SiO_4 concentrations observed along each of the transects. Typically, SiO_4 decreases in the surface waters during this time of year in response to the winter/spring diatom bloom. The SiO_4 decrease is also concomitant with decreases in other nutrients. This did not occur during this period. The surprisingly low SiO_4 concentrations during WF012 are being currently being verified and will be discussed in more detail in the 2001 annual report.

By April (WF014), surface water concentrations of NO_3 and PO_4 had become depleted at the offshore stations along the Boston-Nearfield transect as these nutrients were being taken up by *Phaeocystis* in northeastern Massachusetts Bay (Figure 4-30). Silicate concentrations remained relatively high at these stations, as this nutrient is not used in substantial quantities by *Phaeocystis* in comparison to other phytoplankton taxa (*i.e.* diatoms). Nutrient concentrations at the other stations along that transect and the rest of Massachusetts and Cape Cod Bays remained elevated or had increased from late February levels. A winter/spring centric diatom bloom in Cape Cod Bay led to a decrease in nutrients in February, but the lack of a bloom later in the spring in Cape Cod and Massachusetts Bay (except at those northeastern offshore and boundary stations) resulted in the continued availability of nutrients. By June (WF017), nutrient levels in the surface waters along each of the transects were depleted except at the inshore stations along the Boston-Nearfield transect (Figure 4-31). There was a strong vertical gradient for NO_3 and PO_4 along each of the transects with very low concentrations above the pycnocline (~20 m) and higher concentrations below. Elevated concentrations of nutrients were observed in the western nearfield, coastal and Boston Harbor waters, which were coincident with higher chlorophyll concentrations along the Boston-Nearfield transect. The outfall signature was evident in contour plots of PO_4 and NH_4 along this transect during each of the farfield surveys (Figures 4-31b and 4-32).

Nutrient-salinity plots are often useful in distinguishing water mass characteristics and in examining regional linkages between water masses (Appendix D). Dissolved inorganic nitrogen (DIN) plotted as a function of salinity has been used in past reports to illustrate the transition from winter to summer conditions and back again. Typically in this region winter conditions are represented by a negative correlation between DIN and salinity as the harbor and coastal waters are a source of low salinity, nutrient rich waters and the water column is well mixed. The summer is normally characterized by a positive relationship between DIN and salinity as biological utilization and stratification reduce nutrients to low concentrations in surface waters and concentrations increase with salinity at depth. During February to June of 2001, these patterns were observed, but there was both a regional mix of relationships between DIN and salinity and a new signal of a wide range of DIN concentrations over a narrow salinity band for the nearfield due to the presence of the bay outfall.

During the February surveys (Figure 4-33), a negative relationship between DIN and salinity was observed in Boston Harbor, while a positive relationship was seen at Cape Cod Bay and boundary stations. Coastal and offshore stations exhibited a well-mixed water column and no trends in respect to DIN and salinity. In the nearfield, there was little variation in salinity, but a large range of DIN values that were primarily driven by high NH_4 concentrations in the outfall discharge. By April (WF014), the DIN versus salinity signal exhibited a strong inverse relationship at the Boston Harbor and coastal stations due to increased DIN concentrations and runoff (Figure 4-34a). Low salinity waters were also observed at boundary station F26 off of Cape Ann. Nutrient concentrations at this station were low as they were in the surface waters of the other three boundary stations on or north of Stellwagen Bank (F12, F27, and F28) due to uptake during the *Phaeocystis* bloom. The majority of DIN values were between 5 and 8 μM over a 2 PSU range (30.5 to 32.5 PSU). Elevated DIN concentrations were once again observed at mid-salinity for the nearfield area. In June (WF017), the coastal, Cape Cod Bay, offshore and boundary stations exhibited typical summer conditions with depleted DIN in the surface waters and increasing concentrations at depth with increasing salinity (Figure 4-34b). Elevated DIN concentrations (>10 μM) continued to be observed in the harbor. This was due to increased runoff and nutrient inputs associated with the June 17th rainfall. Maximum DIN concentrations were found in the nearfield during this survey with many values of 10-25 μM.

Nearfield. The nearfield surveys are conducted more frequently and provide a high resolution of the temporal variation in nutrient concentrations over the semi-annual period. In previous sections, the transition from winter to summer physical and nutrient characteristics was considered. For the nearfield, the transition from winter to summer nutrient regimes can be demonstrated by examining contour plots of NO_3 concentrations over time at three representative nearfield stations – N01, N21, and N07 (Figure 4-35). There was a slight decrease in NO_3 concentrations from early to late February, but concentrations increased by the late March nearfield survey (WN013). High NO_3 concentrations continued to be present at the nearfield stations in early April, but by the end of April surface waters were depleted with respect to NO_3 and remained so through June. The continued presence of NO_3 in the nearfield from February through late April is linked to the lack of a large winter/spring bloom in these waters in 2001 and possibly to the availability of NH_4 as a preferred source of nitrogen.

In addition to the availability of NO_3, the discharge from the bay outfall provided a direct source of additional NH_4 and PO_4 to the nearfield in 2001. Figure 4-36 illustrates the use of NH_4 as a natural tracer of the plume during well-mixed and stratified conditions and the effect of increased flow from the outfall during storm events under stratified conditions. The transect extends diagonally across the nearfield from the southwest to the northeast corners. Even though eastern nearfield stations started to stratify in late March (see Figure 4-1), the water column remained mixed in parts of the nearfield until the mid-May survey (WN016). From early February till early April, the NH_4 pattern was similar to that seen during WF014 (Figure 4-36). Elevated NH_4 concentrations were found in the vicinity of station N21 with higher concentrations in the surface waters than at depth. Certainly NH_4 concentrations were higher in the plume near the diffuser, but the spatial extent of the plume is relatively confined at depth during these well-mixed conditions and the sampling procedure was not focused on capturing this signal at depth. By late April (WN015), the water column had become more stratified along the inshore stations of the nearfield transect, but high NH_4 concentrations were still observed in surface waters at station N15. In mid-May, the water column was stratified across the entire nearfield transect and elevated NH_4 concentrations were only found at depths below the pycnocline. This changed in June as flow from the outfall increased in response to the June 17th storm and the effluent NH_4 signal reached into the nearfield surface waters. The highest concentrations, however, were still confined to deeper waters.

An examination of the nutrient-nutrient plots showed that surface waters were generally depleted in DIN relative to PO_4 in the nearfield for the entire semi-annual period (Appendix D). The DIN:PO_4 ratio was generally less than the Redfield value of 16 at the nearfield stations from February to June, but did not become nitrogen limited until mid-May (WN016). For the first two surveys, the nearfield waters were depleted of SiO_4 versus DIN, but concentrations were not limiting. In March and April, concentrations of DIN, PO_4, and SiO_4 continued to be elevated and available to phytoplankton. Not until May did surface water concentrations reach biologically limiting concentrations.

4.2.2 Chlorophyll a

Chlorophyll concentrations (based on calibrated *in situ* fluorescence measurements) were relatively low in Massachusetts and Cape Cod Bay from February to June 2001 in comparison to baseline years. The highest chlorophyll concentrations were observed in early February in Cape Cod Bay. Boundary, offshore, and nearfield maxima were also measured in early February. The maximum mean concentrations in coastal waters occurred in late February, while Boston Harbor chlorophyll concentrations peaked in June. The nearfield mean areal chlorophyll (basis for chlorophyll threshold) for the winter/spring (February through April) of 2001 was 68.96 mgm^{-2}, which is well below the seasonal caution threshold of 182 mgm^{-2}. This is a departure from the very high areal chlorophyll values seen winter/spring 1999 (176 mgm^{-2}) and 2000 (191 mgm^{-2}). The high winter/spring chlorophyll concentrations were coincident with large winter/spring diatom and *Phaeocystis* blooms of 1999 and 2000, respectively. The lack of a major winter/spring bloom in 2001 resulted in lower chlorophyll concentrations in the nearfield.

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were relatively high across most of the region during the two surveys in February. In early February (WF011), surface chlorophyll values were >3 μgL^{-1} in the nearfield, at boundary station F26, and in Cape Cod Bay where the highest surface chlorophyll concentration was observed (9.8 μgL^{-1} at station F02; Figure 4-37). The high chlorophyll concentrations in Cape Cod Bay were coincident with high phytoplankton abundance (see Figure 5-18). Lower concentrations (<1 μgL^{-1}) were observed in Boston Harbor and coastal waters along the south shore. By late February (WF012), surface chlorophyll concentrations in Cape Cod Bay had decreased to 2-4.7 μgL^{-1}, but the highest concentrations were found at stations F26 and F27 off of Cape Ann (5.0 μgL^{-1} and 4.8 μgL^{-1}, respectively; Figure 4-38). This increase correlated with an increase in centric diatoms in surface and mid-depth waters, but total phytoplankton abundance remained relatively low at these stations (<0.5 million cells/L^{-1}) as it did throughout Massachusetts Bay. The elevated surface chlorophyll concentrations in Cape Cod Bay were coincident with low nutrient concentrations in comparison to Massachusetts Bay. Surface chlorophyll concentrations decreased from the relatively high values in northern Massachusetts Bay and Cape Cod Bay to low values in the nearfield, southern Massachusetts Bay, and Boston Harbor.

As mentioned in Section 4.2.1.1, SiO4 concentrations were relatively low during the late February survey and suggest biological uptake of the nutrient over the course of the month. The timing of the surveys may have been such that a bloom event was missed. Unfortunately, ancillary data from SeaWiFS images and the USGS mooring are scant for February 2001. Both suggest a decrease in chlorophyll concentrations from mid-February to late February. The SeaWiFS image from February 10 shows relatively high surface chlorophyll concentrations of 3-10 μgL^{-1} in Massachusetts Bay (higher in Cape Cod Bay; Figure 4-39). By February 26, chlorophyll concentrations had decreased to <3 μgL^{-1} throughout the bay (Figure 4-40). The mooring data indicated that chlorophyll concentrations at mid-depth were 3 μgL^{-1} on February 14 and 15 before declining to ~2 μgL^{-1} for the remainder of the month (see Figure 3-2). There are no high-resolution data for the surface waters. Survey, mooring, and satellite data did not capture trends in surface water chlorophyll for February and it is unclear why a large decrease in SiO_4 concentrations was observed.

During the April survey (WF014), surface chlorophyll concentrations were very low (<0.5 μgL^{-1}) in southern Massachusetts Bay, Cape Cod Bay, and at boundary stations. The maximum surface chlorophyll concentration was at nearfield station N05 (2.28 μgL^{-1}) and concentrations of >1 μgL^{-1} only occurred in the nearfield and at station F23 in Boston Harbor. The relatively low surface chlorophyll values in early April are surprising given the availability of nutrients, relatively high areal production at station N04 and N18 (highest of period), and the minor *Phaeocystis* bloom observed throughout Massachusetts Bay. Surface phytoplankton abundance was about 1 million cells L^{-1} in the nearfield and reached 2.5 million cells L^{-1} at boundary station F27, but there was not a commensurate increase in chlorophyll (although NO_3 and PO_4 concentrations were lower at the boundary stations indicative of more biological uptake). SeaWiFS images indicated that chlorophyll concentrations were high (~5 μgL^{-1}) in the vicinity of Cape Ann and extending into northern Massachusetts Bay in early April (see Appendix I). Although surface chlorophyll concentrations at stations F26 and F27 were low, they increased quickly with depth to 5-7 μgL^{-1} in the upper 10m, which is the nominal depth for SeaWiFS. In Cape Cod Bay, chlorophyll concentrations had decreased sharply from late February to April and were essentially at detection limits. *Phaeocystis* was present in very low abundance in Cape Cod Bay during the April survey.

Nearfield surface chlorophyll remained low from early April through May. In late April (WN015), surface chlorophyll concentrations ranged from 0.14 to 2.6 μgL^{-1} with the highest concentration found at the inshore station N01. Surface chlorophyll remained low in May ranging from 0.13-1.6 μgL^{-1} with the maximum at station N10 and values decreasing further offshore. The decrease in nearfield surface chlorophyll concentrations from early to late April was associated with a decrease in production at station N04 and N18 and a decrease in phytoplankton abundance and end of *Phaeocystis* bloom. By mid-May, chlorophyll concentrations and production remained low, but phytoplankton abundance had more than doubled primarily due to an increase in centric diatoms (see Figure 5-16).

By June (WF017), the phytoplankton assemblage throughout the farfield was dominated by microflagellates and the regional pattern in surface chlorophyll generally decreased from inshore to offshore. Chlorophyll concentrations at the Boston Harbor and near-harbor coastal stations were high reaching a maximum of 4.83 μgL^{-1} at station F30 and decreasing to ~1 μgL^{-1} in the western nearfield. Chlorophyll values decreased further offshore to <1 μgL^{-1} in the eastern nearfield, offshore, boundary, and Cape Cod Bay areas. This was coincident with an inshore to offshore decrease in nutrient concentrations and NO_3 depletion in the surface waters throughout the bays. The high harbor and coastal chlorophyll concentrations were coincident with the period maximum in production at station F23 and elevated phytoplankton abundance, which also exhibited an inshore to offshore decrease (see Figure 5-21).

4.2.2.2 Vertical Distribution

Farfield. The vertical distribution of chlorophyll was evaluated using vertical contours of *in situ* fluorescence data collected along three east/west transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). In early February (WF011), chlorophyll concentrations along the transects exhibited a similar pattern to surface chlorophyll (see Figure 4-37) with elevated concentrations at boundary stations off of Provincetown and Cape Ann and in the nearfield. The elevated chlorophyll concentrations (3-6 μgL^{-1}) observed in the nearfield appeared to extend down to the Cohasset and Marshfield transects as well (Figure 4-41). By late February (WF012), chlorophyll concentrations had decreased to 1-3 μgL^{-1} along each of the transects with higher concentrations along the boundary transect. The highest concentrations (4-6 μgL^{-1}) were found in the upper 20 meters at boundary station F26 and F27 off of Cape Ann (Figure 4-42a).

In April (WF014), surface chlorophyll concentrations had decreased substantially, but a more clearly defined subsurface chlorophyll maximum was observed along each of the transects. Along the Boston-Nearfield transect, surface chlorophyll concentrations were low ranging from 0-2 μgL^{-1} and were not much higher in the subsurface chlorophyll maximum in coastal and nearfield waters (Figure 4-42b). There was an increase in subsurface chlorophyll concentrations from inshore to offshore reaching a maximum of 5-7 μgL^{-1} at 10-20 m at boundary station F27. A similar pattern was seen along the Cohassett transect with the highest chlorophyll concentrations (2-5 μgL^{-1}) in the subsurface chlorophyll maximum at the stations further offshore. Further to the south along the Marshfield transect, chlorophyll values were lower 0-1 μgL^{-1} in the surface waters and only 1-2 μgL^{-1} at the subsurface maximum. The chlorophyll and phytoplankton data were generally consistent with the higher chlorophyll concentrations and phytoplankton abundance occurring at boundary stations F26 and F27 and offshore station F22 (see Figure 5-20). The phytoplankton assemblage was dominated by *Phaeocystis* at these stations and abundances and chlorophyll concentrations were higher in the subsurface chlorophyll maximum.

By June (WF017), the patterns along the transects showed the typical progression to summer conditions of elevated surface chlorophyll concentrations near Boston Harbor and coastal waters and clearly defined subsurface maxima along the pycnocline further offshore (Figure 4-42c). A pattern similar to and of the same magnitude of the chlorophyll concentrations along the Boston-Nearfield transect was observed along the Cohasset and Marshfield transects (see Appendix C). The elevated chlorophyll concentrations in the surface and mid-depth waters in Boston Harbor and at coastal stations was coincident with high phytoplankton abundance, but abundances were relatively low in the subsurface chlorophyll maximum offshore. The higher chlorophyll concentrations in the offshore subsurface maximum were likely due to a physiological response to low light rather than an indicator of biomass.

Nearfield. Chlorophyll concentrations for the surface, mid-depth, and bottom waters of all nearfield stations were averaged and plotted for each of the nearfield surveys (Figure 4-43). The mid-depth sample was collected at the subsurface chlorophyll maximum, if present. The mean chlorophyll concentrations were relatively high (~4 μgL^{-1}) in the surface and mid-depth waters in early February and only slightly lower in the bottom water (2.75 μgL^{-1}). The early February values were the highest measured for each depth over the February to June 2001 time period. Chlorophyll concentrations decreased from early February to late March reaching mean concentrations of <1 μgL^{-1} at each depth on March 26th. By April, nearfield mean chlorophyll values had increased to 2.25 μgL^{-1} at mid-depth, but remained around 1 μgL^{-1} in the surface and bottom waters. These low chlorophyll concentrations occurred despite a 2-3 fold increase in phytoplankton abundance in surface and mid-depth waters during the *Phaeocystis* bloom and seasonal peaks in production at stations N04 and N18 (see Figures 5-16 and 5-17). By late April (WN015), mid-depth chlorophyll concentrations had decreased to 2 μgL^{-1} and surface and bottom water concentrations to ~0.5 μgL^{-1}. In late April following the WN015 survey, there was a sharp increase in mid-depth chlorophyll concentrations that was evident in the mooring data (see Figure 3-2). The mooring data show a 3-fold increase in chlorophyll from 2 μgL^{-1} on April 26 to 6 μgL^{-1} May 5 and then a subsequent decrease to 1 μgL^{-1} over the ensuing week. These temporally high-resolution data may be indicative of either the transitory nature of chlorophyll 'events' or perhaps a deepening of the pycnocline and associated subsurface maximum. As the data are only available at one depth, it is difficult to determine which was the case during this time period.

By mid-May (WN016), chlorophyll concentrations had decreased at mid-depth to 1.5 μgL^{-1} and remained low (0.5 μgL^{-1}) in the surface and bottom waters. The low mean surface chlorophyll concentration was coincident with a >2-fold increase in phytoplankton abundance from late April to mid-May due predominantly to increases in centric diatoms. It is unclear why there was not a concomitant increase in surface chlorophyll. However, production was low during this survey. Thus the lack of an increase in chlorophyll may be due to senescent cells that have become physiologically adapted to light conditions. Logan Airport weather reports indicate that May 2001 was especially clear and sunny. Nearfield chlorophyll concentrations increased to 3 μgL^{-1} in mid-depth waters by June, while remaining low in surface and bottom waters.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in dissolved oxygen (DO) concentrations were evaluated for the entire region (Section 4.2.3.1) and for the nearfield area (Section 4.2.3.2). DO concentrations in 2001 were within the range of values observed during previous years and followed typical trends. Due to the relative importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. The minimum measured DO concentration was 7.31 mgL^{-1} in Cape Cod Bay in June (WF017). The nearfield minimum of 8.40 mgL^{-1} was also observed in June. DO concentrations were within the range of values observed during previous years. The June bottom water concentrations in 2001 were comparable to 2000 values for most areas and slightly higher (~1 mgL^{-1}) for the offshore and boundary waters. Although there was an extraordinary *Phaeocystis* bloom in 2000, September/October 2000 bottom water DO concentrations were relatively high in comparison to baseline data. Physical factors relating to establishment of stratified conditions and ventilation likely alleviated a potentially problematic DO situation in 2000. The lack of a substantial winter/spring bloom in 2001 and relatively high bottom water DO concentrations in June suggest that DO concentrations will not be detrimental in fall 2001 barring any anomalous summer events. It has been suggested that regional factors may play an important role in the control of nearfield bottom water DO concentrations. These regional factors are currently being evaluated and will be discussed in detail in the nutrient issues review.

4.2.3.1 Regional Trends of Dissolved Oxygen

The DO in bottom waters was compared between areas and over the course of the four combined surveys. A time series of the average bottom water DO concentration for each area is presented in Figure 4-44a. Average bottom water DO concentrations ranged from 8 to 12 mgL^{-1}. Bottom water DO concentrations were high (10.3 to 11.5 mgL^{-1}) in early February and increased in each area as of the late February survey. Lower concentrations were consistently observed at the deeper boundary and offshore areas over these two surveys. In late February, bottom water DO concentration was lowest (10.5 mgL^{-1}) in the boundary area, ~11 mgL^{-1} in coastal and offshore waters, 11.5 mgL^{-1} in Boston Harbor, and highest at 11.8 mgL^{-1} in Cape Cod Bay. By early April, bottom water DO concentrations had decreased throughout the bays. In Cape Cod Bay, bottom water DO concentrations decreased by almost 2 mgL^{-1} from late February to early April. This was likely related to the decline of the centric diatom bloom as indicated by chlorophyll and phytoplankton data at the Cape Cod Bay stations in February. Harbor and offshore bottom water concentrations decreased by ~1 mgL^{-1} and coastal and boundary concentrations by ~0.5 mgL^{-1} over this time period. Between the April and June surveys, the decline in bottom water DO continued at Boston Harbor, coastal and Cape Cod Bay stations. In Boston Harbor and Cape Cod Bay, bottom water DO concentrations declined by ~3 mgL^{-1} from late February to June. Coastal bottom water concentrations had declined by ~1.5 mgL^{-1} from early April to June. In contrast, offshore bottom water DO concentrations were unchanged from April levels and concentrations actually increased by almost 1 mgL^{-1} at the boundary stations. The decline observed in 2001 was comparable to that seen during 2000 and may be an indication that bottom water DO concentrations may not achieve very low levels as seen in the fall of 2000.

Typically, there is a trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter/spring bloom in the bays. This was the case in Boston Harbor, Cape Cod Bay, and coastal (and nearfield) waters, but not at the deeper offshore and boundary stations. These waters are more greatly affected by regional factors (i.e. Gulf of Maine) and the increase and stabilization of bottom water DO concentrations from April to June may have been due to influences outside of Massachusetts Bay. The distribution of bottom water DO concentrations is presented in Figure 4-45, which clearly shows the lower concentrations in Boston Harbor, nearby coastal waters, and Cape Cod Bay and the higher concentrations in northeastern Massachusetts Bay. The pattern of elevated bottom water DO concentrations suggests an offshore influence. The role of regional factors is currently being evaluated and will be discussed in detail in an upcoming nutrient issues review.

The trend of decreasing DO in the bottom waters was less apparent in the DO %saturation data (Figure 4-44b). In general, DO %saturation increased from early February to late February, decreased in each of the areas from late February to April, and then continued to decrease in the harbor, coastal and Cape Cod Bay waters, but increased in the offshore and boundary areas. Bottom waters were generally saturated to supersaturated during the February surveys and then at or below 100% saturation in April and June. The main deviation from these trends was the super saturation at boundary stations in June, which increased from 95% saturation in April to 105% in June. In June, bottom waters were slightly under saturated with respect to DO in harbor, coastal, and offshore waters with average values of ~98% saturation. The lowest DO %saturation was observed in Cape Cod Bay (92% saturation).

4.2.3.2 Nearfield Trends of Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation values for both the surface and bottom waters of the 21 nearfield stations were averaged and plotted for each of the nearfield surveys. Maximum surface and bottom water DO concentrations were observed in early February (Figure 4-46a). From early February to late March, the average surface water DO concentrations for the nearfield area varied decreased from ~11.3 to almost 10.5 mgL^{-1}, while average bottom water concentration decreased from 10.9 to 10.1 mgL^{-1}. By early April (WF014), surface and bottom water DO concentrations had increased by ~0.5 mgL^{-1} coincident with an increase in production (period maximum at both stations N04 and N18) and phytoplankton abundance during minor Phaeocystis bloom. Nearfield average DO concentrations decreased from early April to June when minima were attained in both surface and bottom waters. A combination of high surface water temperatures and low salinity due to surface runoff led to the average surface water DO concentration being lower that the bottom water concentration. The lack of a major spring bloom and the associated delivery of organic carbon to the benthos and bottom waters probably contributed to the presence of relatively high bottom water DO concentrations in June 2001.

The average DO %saturation for the surface waters followed the same decreasing trend as DO concentration from early February to late March (Figure 4-46b). The surface and bottom waters were slightly super saturated with respect to DO in February (102-106%) and decreased in March reaching under saturated levels (95-98%). By early April, surface water DO %saturation had increased to 105% saturation and bottom water had returned to 100% saturation. From early April to June, surface waters remained supersaturated at levels of 110±3% for the rest of the time period. There was little variation in average DO %saturation for the bottom waters from late April to June ranging from 94 to 97% saturation.

4.3 Contingency Plan Thresholds

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions. Those parameters include background levels for water quality parameters chlorophyll and dissolved oxygen. Annual and seasonal chlorophyll areal concentration thresholds have been developed for the nearfield area and bottom water dissolved oxygen concentration and percent saturation minima thresholds have been designated for the nearfield and Stellwagen Basin (Table 4-1). For the first half of 2001, the only threshold to be examined is the seasonal areal chlorophyll threshold for winter/spring 2001. The winter/spring 2001 mean areal chlorophyll was 69 mg m^{-2} well below the caution threshold of 182 mg m^{-2} (Table 4-1). The relatively low areal chlorophyll value for winter/spring 2001 is due to the lack of a large winter/spring bloom, which has occurred in Massachusetts Bay during 6 out of 9 years of baseline monitoring.

Table 4-1. Contingency plan threshold values for water quality parameters.

Parameter	Time Period	Caution Level	Warning Level	Background	2001
Bottom Water DO concentration	Survey Mean in June-October	< 6.5 mg/l (unless background lower)	< 6.0 mg/l (unless background lower)	Nearfield - 5.75 mg/l Stellwagen - 6.2 mg/l	na
Bottom Water DO %saturation	Survey Mean in June-October	< 80% (unless background lower)	< 75% (unless background lower)	Nearfield - 64.3% Stellwagen - 66.3%	na
Chlorophyll	Annual	107 mg/m^2	143 mg/m^2	--	na
	Winter/spring	182 mg/m^2	--	--	69 mg/m^2
	Summer	80 mg/m^2	--	--	na
	Autumn	161 mg/m^2	--	--	na

4.4 Summary of Water Column Results

- Stratification was observed during the April combined survey in Boston Harbor, offshore, and boundary stations. Stratification at these stations was driven by a decrease in surface salinity due to March/April runoff, as surface and bottom water temperatures remained relatively unchanged. At coastal and Cape Cod Bay stations, density and salinity decreased from early March to April, but to similar degrees in both surface and bottom waters resulting in weaker April stratification. By June, surface water temperatures had increased by >10°C throughout the bays and there continued to be a relatively large salinity gradient. These conditions resulted in a strong density gradient in Cape Cod Bay and offshore and boundary areas of Massachusetts Bay. Boston Harbor and coastal waters were less stratified.
- In the nearfield, the water column had begun to stratify in late March at the deeper eastern nearfield stations, but remained well mixed further inshore. In early April, a localized mixing event in the nearfield was evident in the data. This may have been related to increased flow from the outfall discharge as a result of late March rain events. By late April, the water column had become stratified across all of the nearfield area, but it was not until June that a strong density gradient ($\Delta\sigma_t$ >2) was established across the nearfield area.
- The nutrient data for February to June 2001 generally followed the "typical" progress of seasonal events in the Massachusetts and Cape Cod Bays.
  - Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited.
  - A winter/spring 'diatom bloom' reduced nutrient concentrations in Cape Cod Bay surface waters in February.
  - The minor winter/spring *Phaeocystis* bloom in Massachusetts Bay in early April did not lead to reduced nutrient concentrations except at boundary station F26 and F27 where the *Phaeocystis* abundance was highest.

  - Massachusetts Bay nutrient concentrations decreased from early February through April, but did not reach depleted levels in surface waters until June.
- The transfer of effluent discharge from the harbor outfall to Massachusetts Bay outfall reduced the harbor signal of elevated nutrient concentrations (especially NH_4) that had been observed throughout the baseline period. Elevated concentrations of NO_3 and SiO_4 were still observed at the inner harbor station F30 due to riverine inputs.
- The effluent nutrient signal was clearly evident in the nearfield as elevated NH_4 and PO_4 concentrations. Ammonium concentrations are a good tracer, albeit not a conservative tracer, of the effluent plume in the nearfield.
- Chlorophyll concentrations in the nearfield were relatively low in 2001. The nearfield mean areal chlorophyll for winter/spring 2001 of 69 mg m^{-2} well below the caution threshold of 182 mg m^{-2}.
- Chlorophyll concentrations peaked in early February and were highest in Cape Cod Bay coincident with the winter/spring diatom bloom. There was no large increase in chlorophyll associated with the minor bloom of *Phaeocystis* in Massachusetts Bay in April.
- DO concentrations in 2001 were within the range of values observed during previous years and followed the typical trends:
  - In February, the water column was well mixed and DO concentrations were high across the entire region.
  - DO concentrations in the nearfield increased from late March to early April because of increased productivity.
  - The lack of a major winter/spring bloom in Massachusetts and regional influence of the Gulf of Maine led to relatively high bottom water DO concentrations in June. The lowest bottom water DO concentrations were found in Cape Cod Bay. This area is far from the influence of the Gulf of Maine and experienced a winter/spring diatom bloom in February.

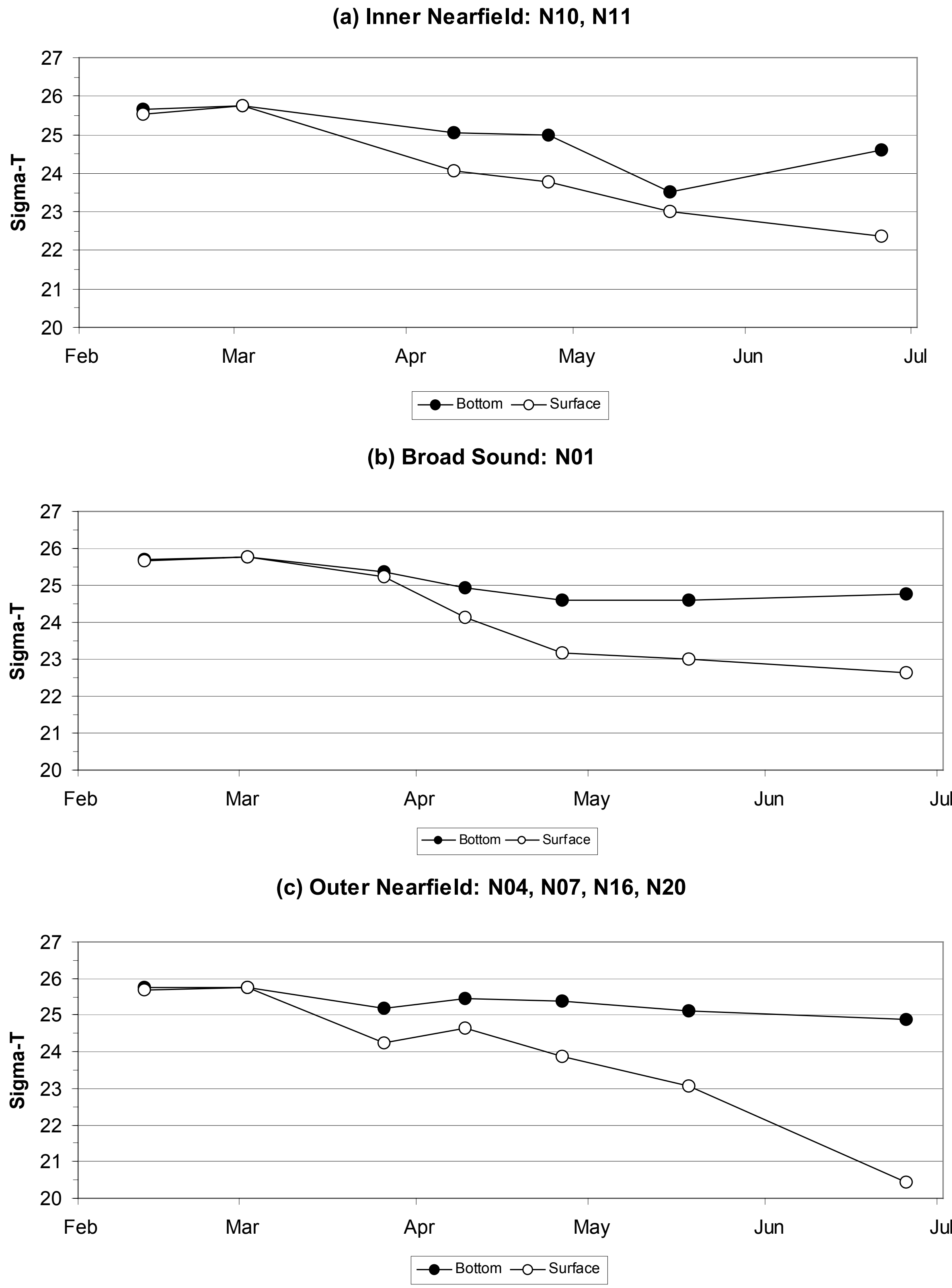


Figure 4-1. Time-Series of Average Surface and Bottom Water Density (σ_t) in the Nearfield

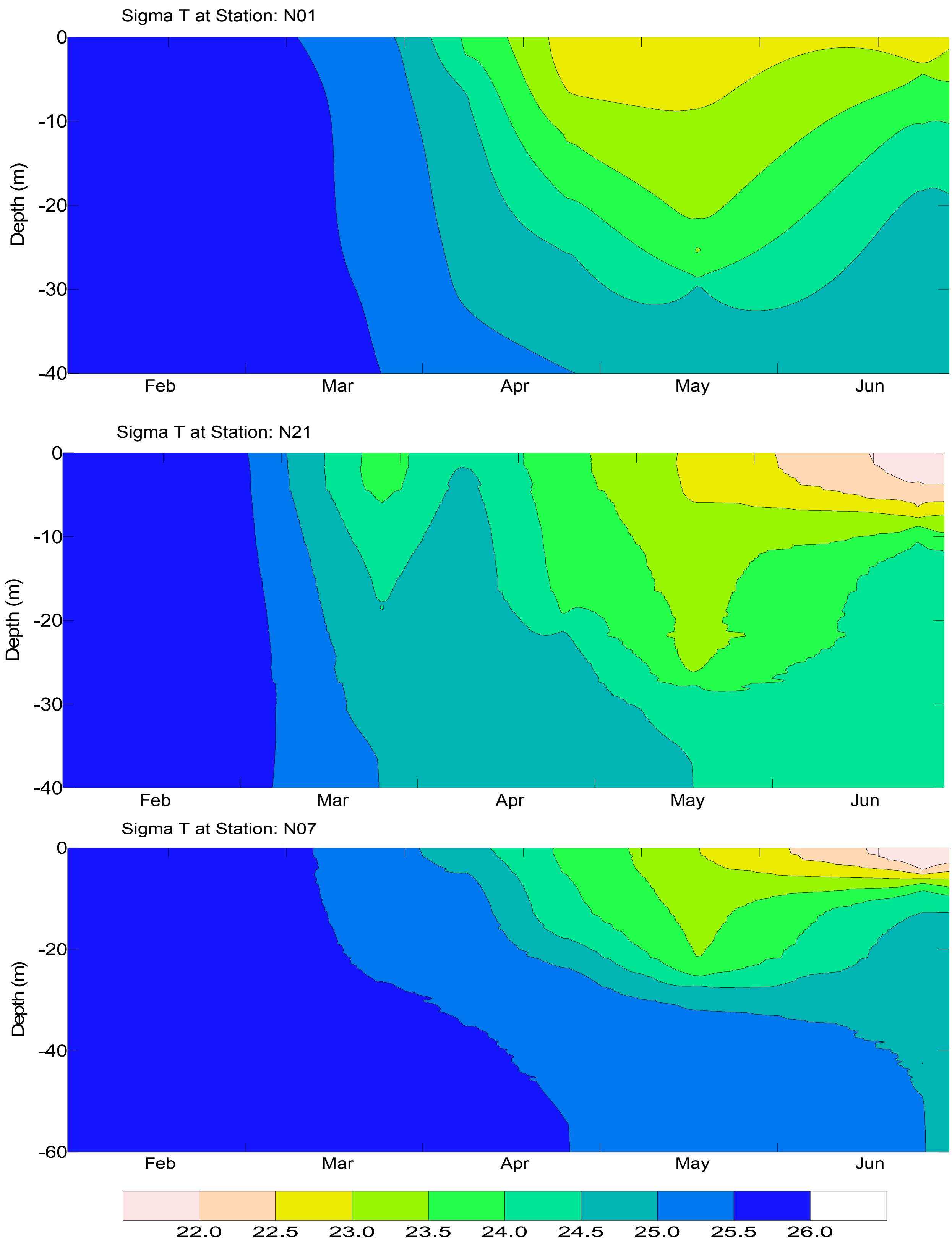


Figure 4-2. Nearfield Depth vs. Time Contour Plots of Density (σ_t) for Stations N01, N21, and N07

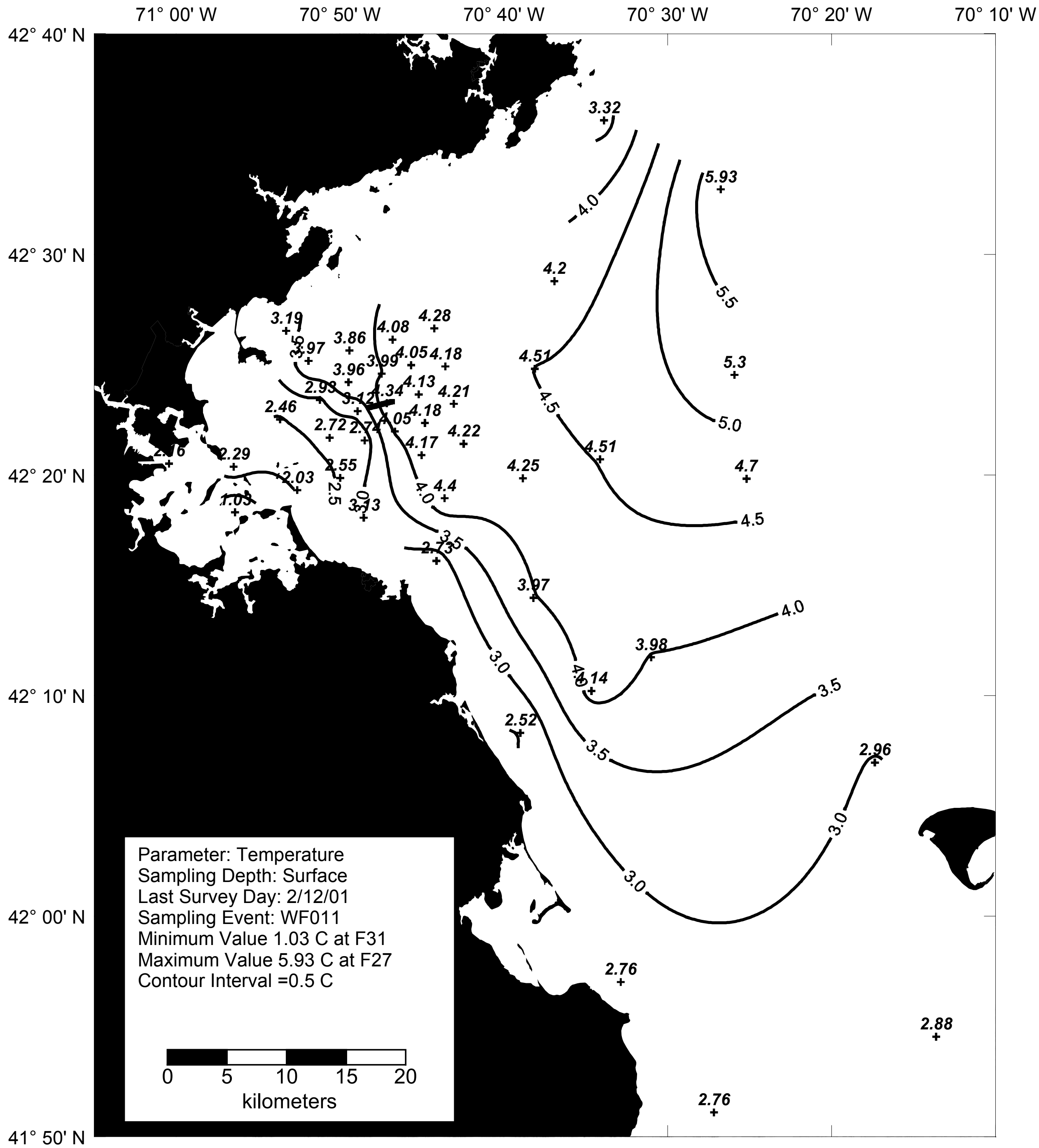


Figure 4-3. Temperature Surface Contour Plot for Farfield Survey WF011 (Feb 01)

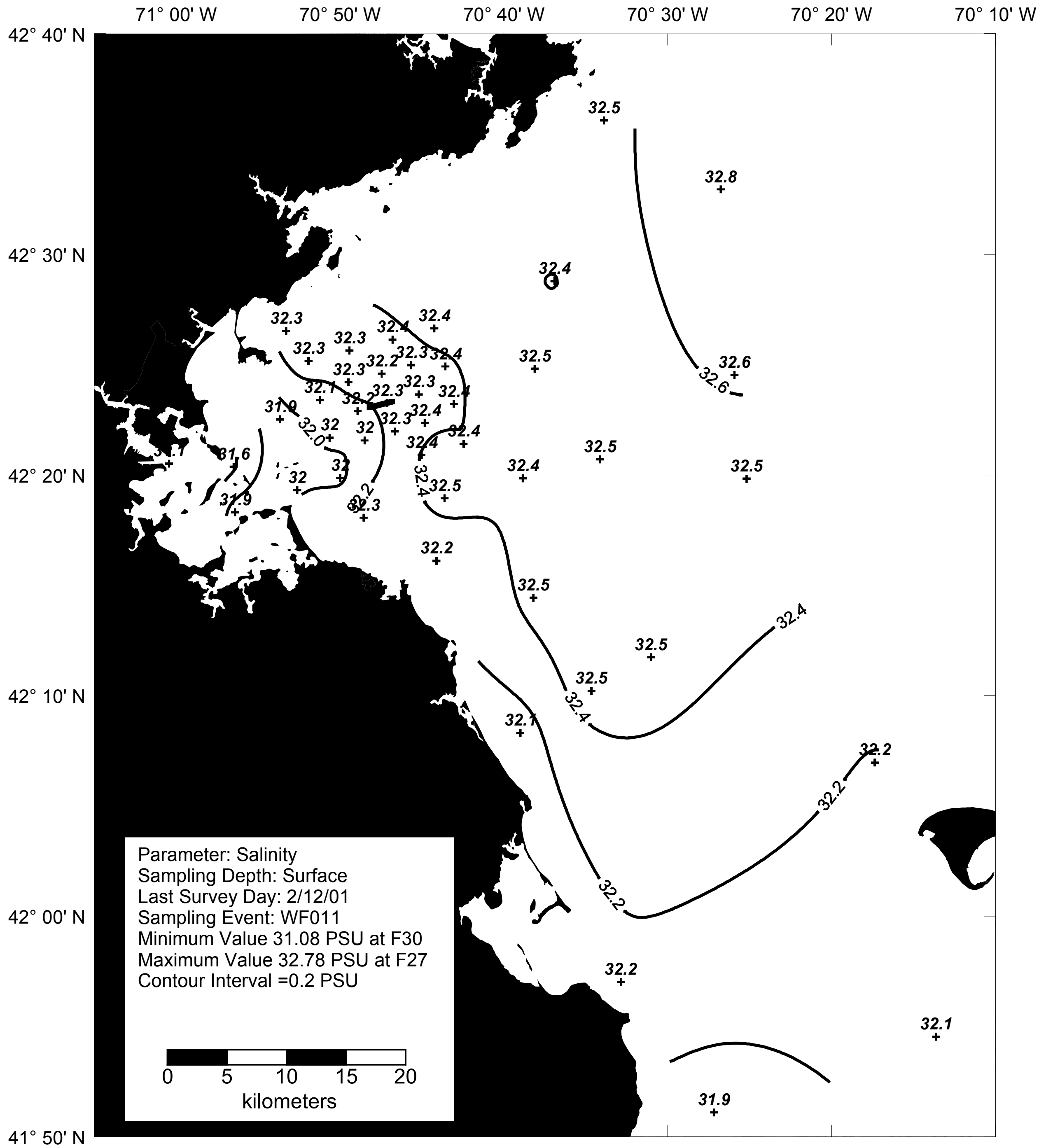


Figure 4-4. Salinity Surface Contour Plot for Farfield Survey WF011 (Feb 01)

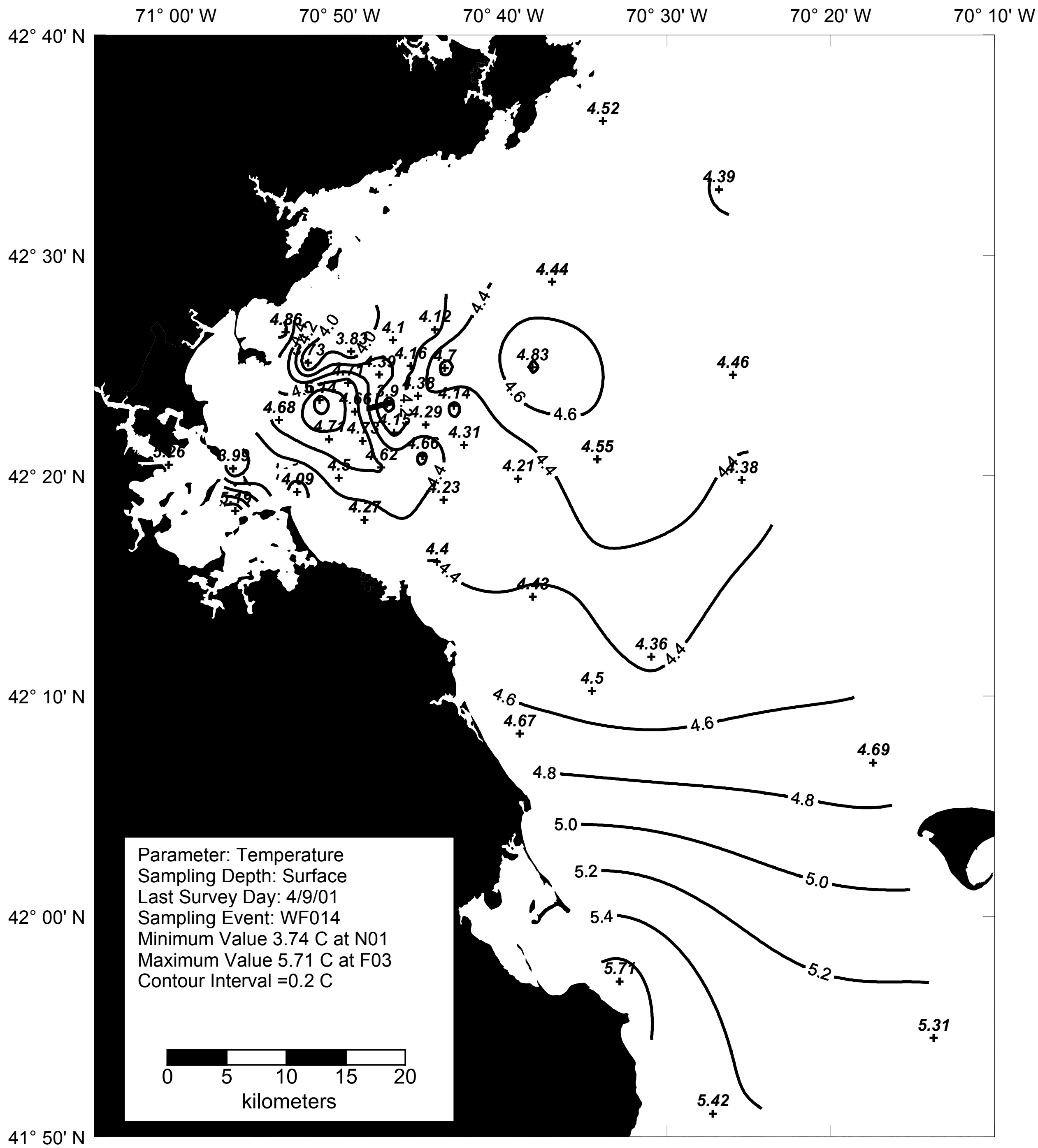


Figure 4-5. Temperature Surface Contour Plot for Farfield Survey WF014 (Apr 01)

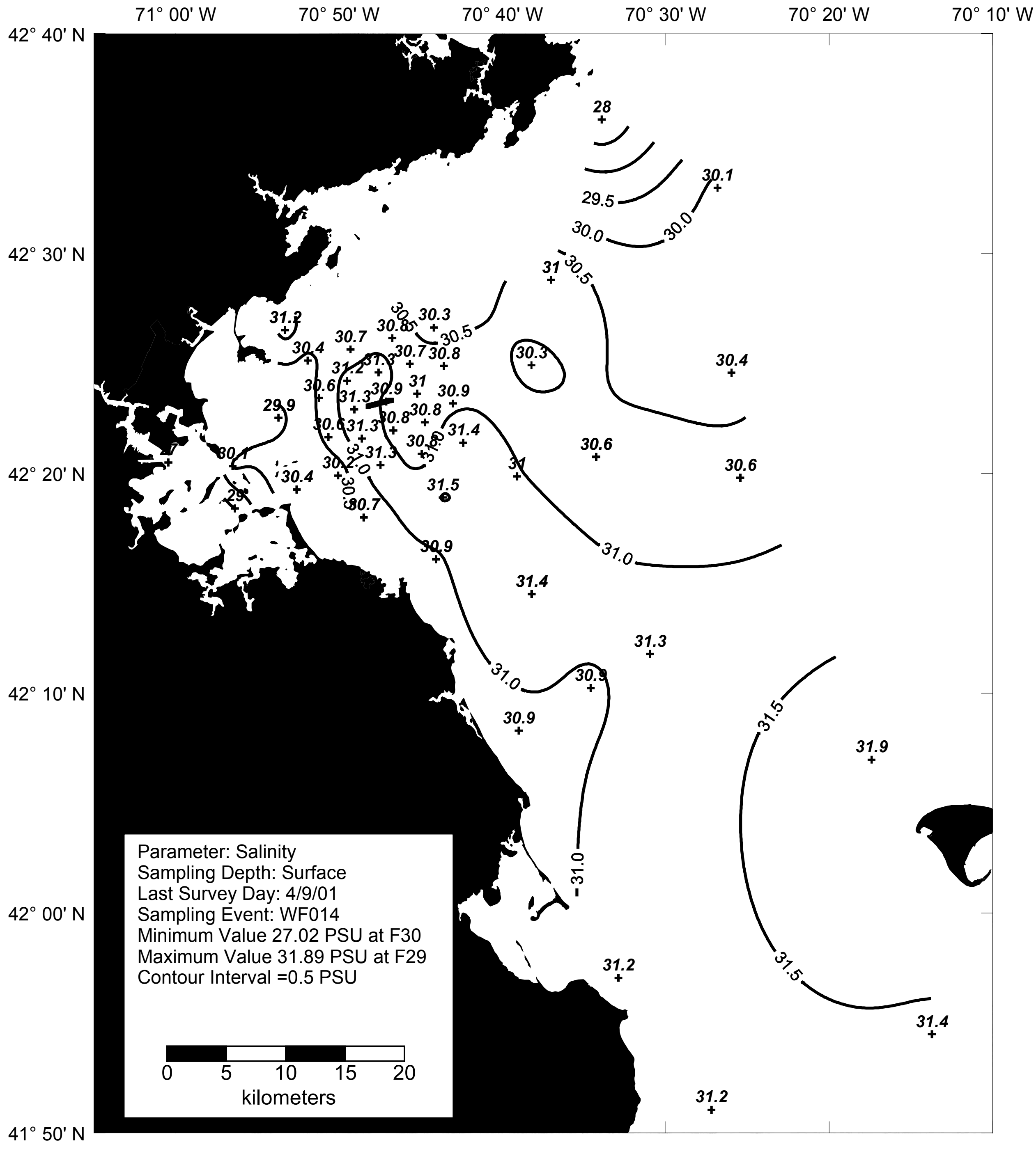


Figure 4-6. Salinity Surface Contour Plot for Farfield Survey WF014 (Apr 01)

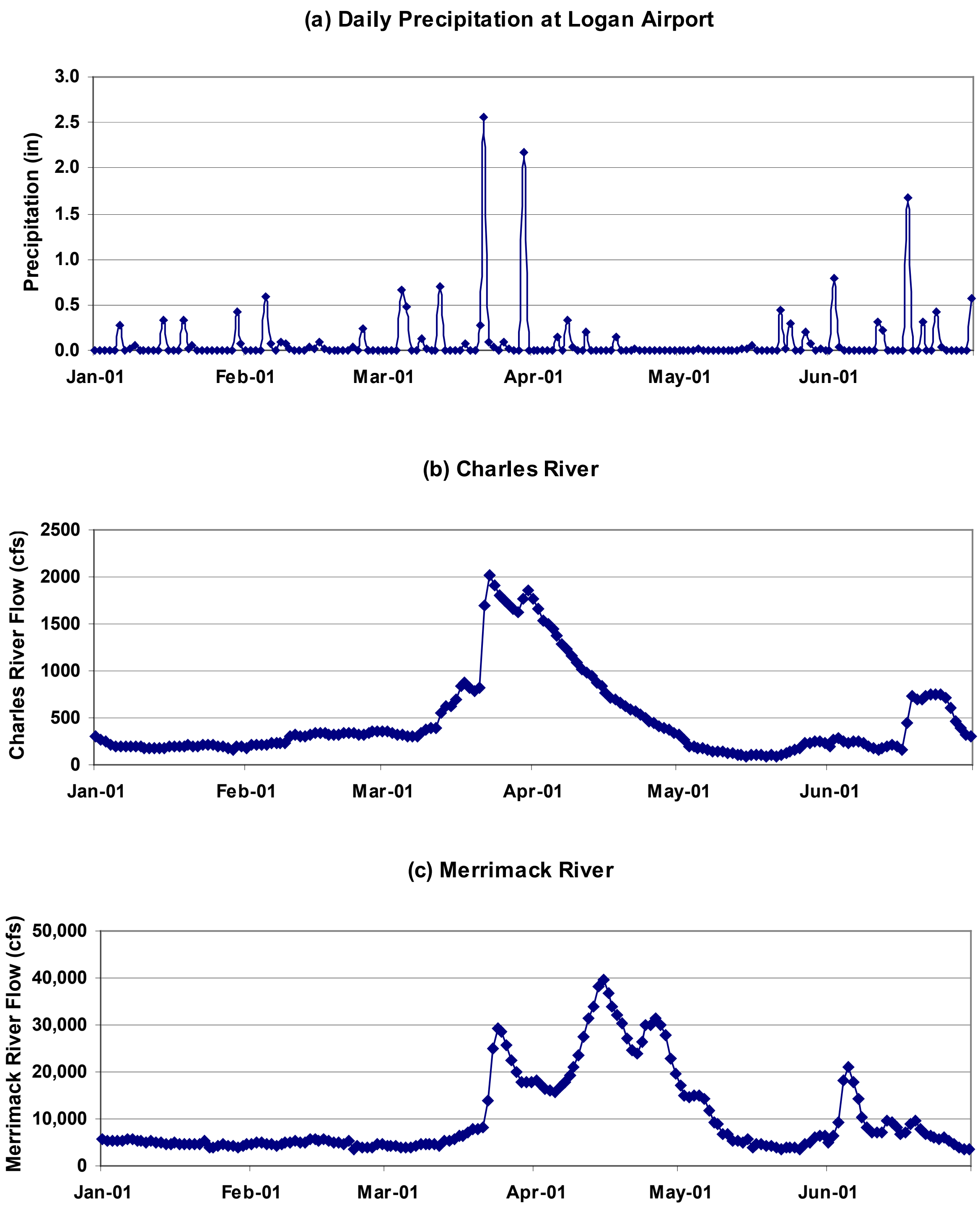


Figure 4-7. Precipitation at Logan Airport and River Discharges for the Charles and Merrimack Rivers

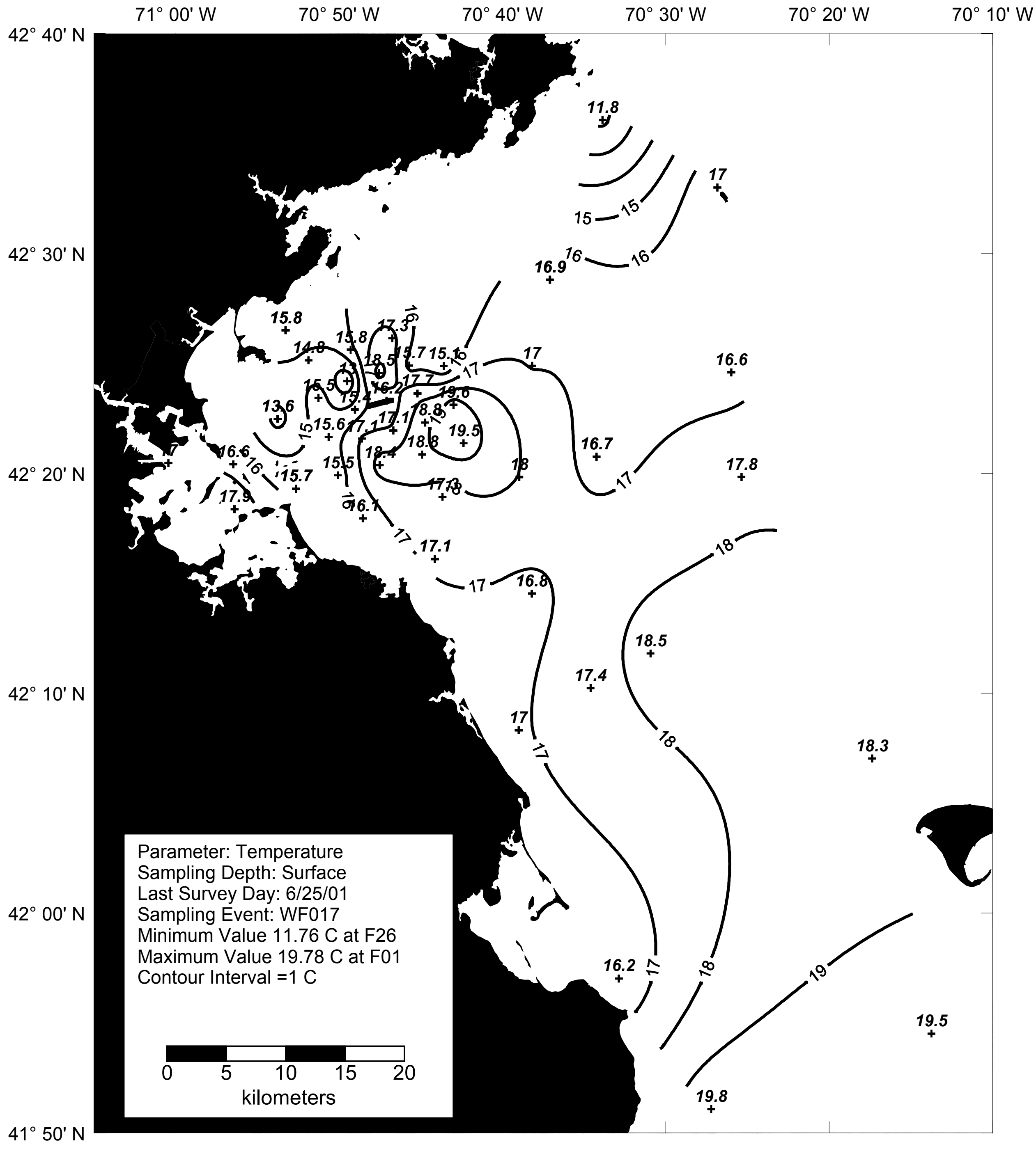


Figure 4-8. Temperature Surface Contour Plot for Farfield Survey WF017 (Jun 01)

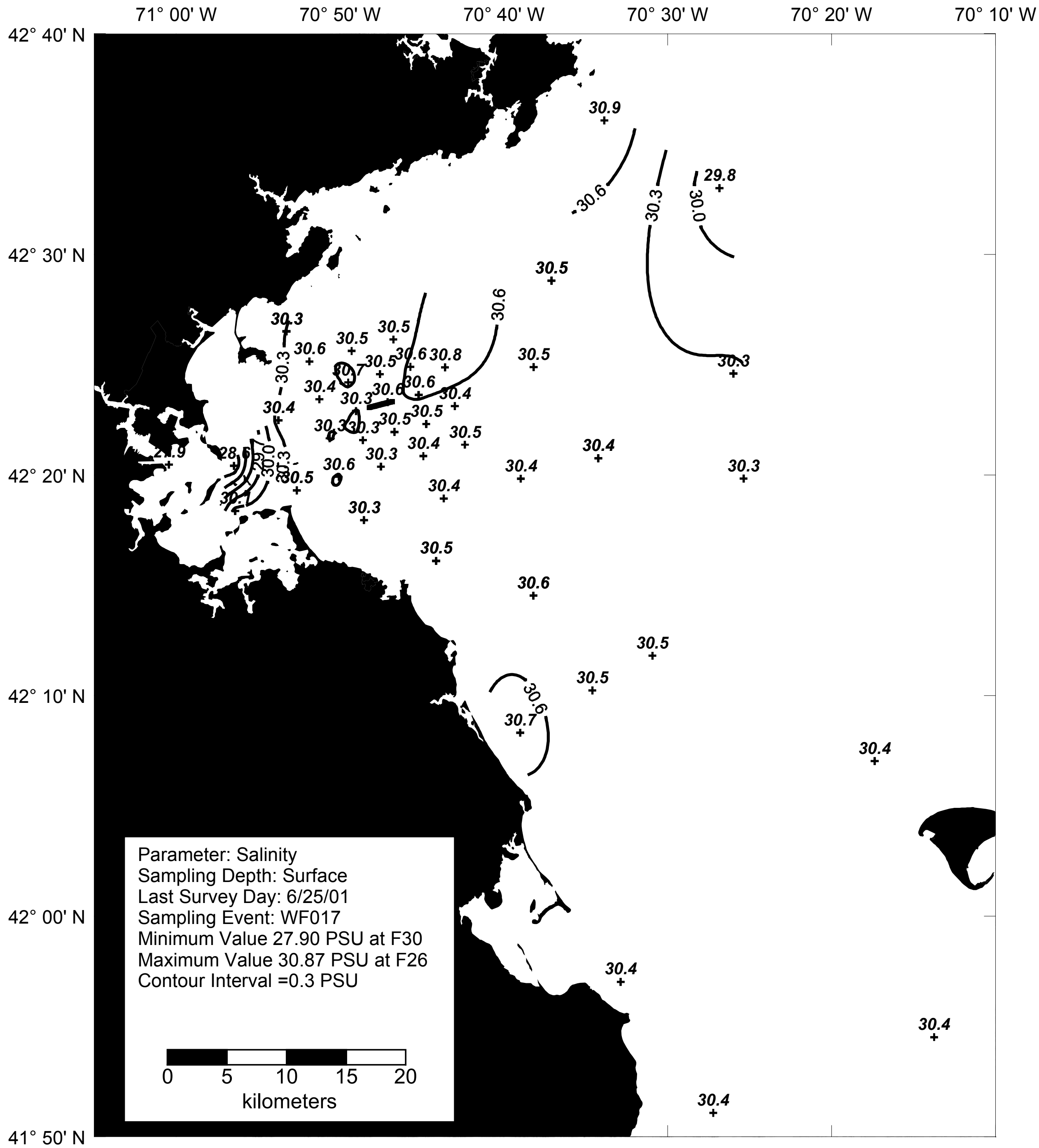


Figure 4-9. Salinity Surface Contour Plot for Farfield Survey WF017 (Jun 01)

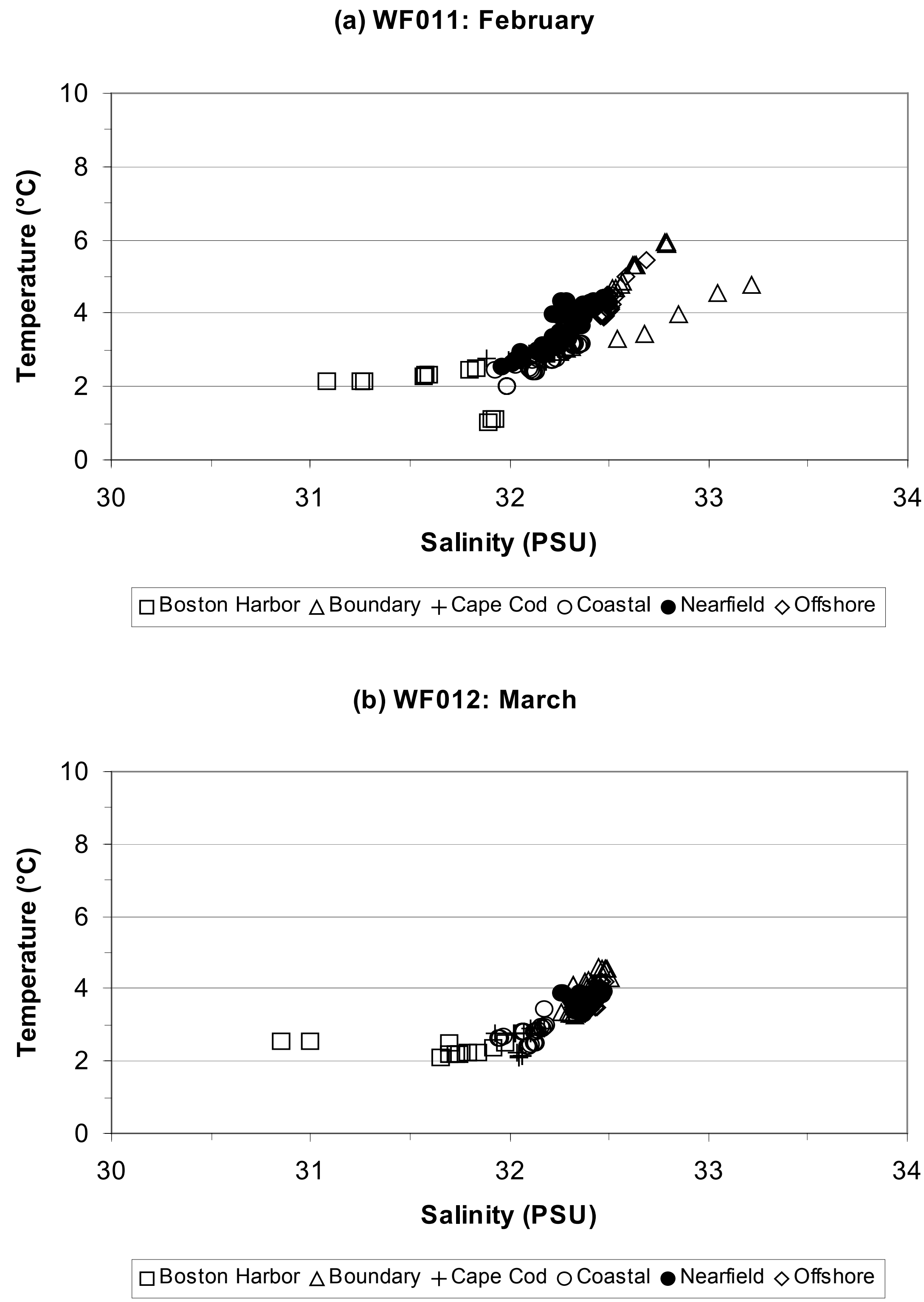


Figure 4-10. Temperature/Salinity Distribution for All Depths during WF011 (Feb 01) and WF012 (Feb/Mar 01) Surveys

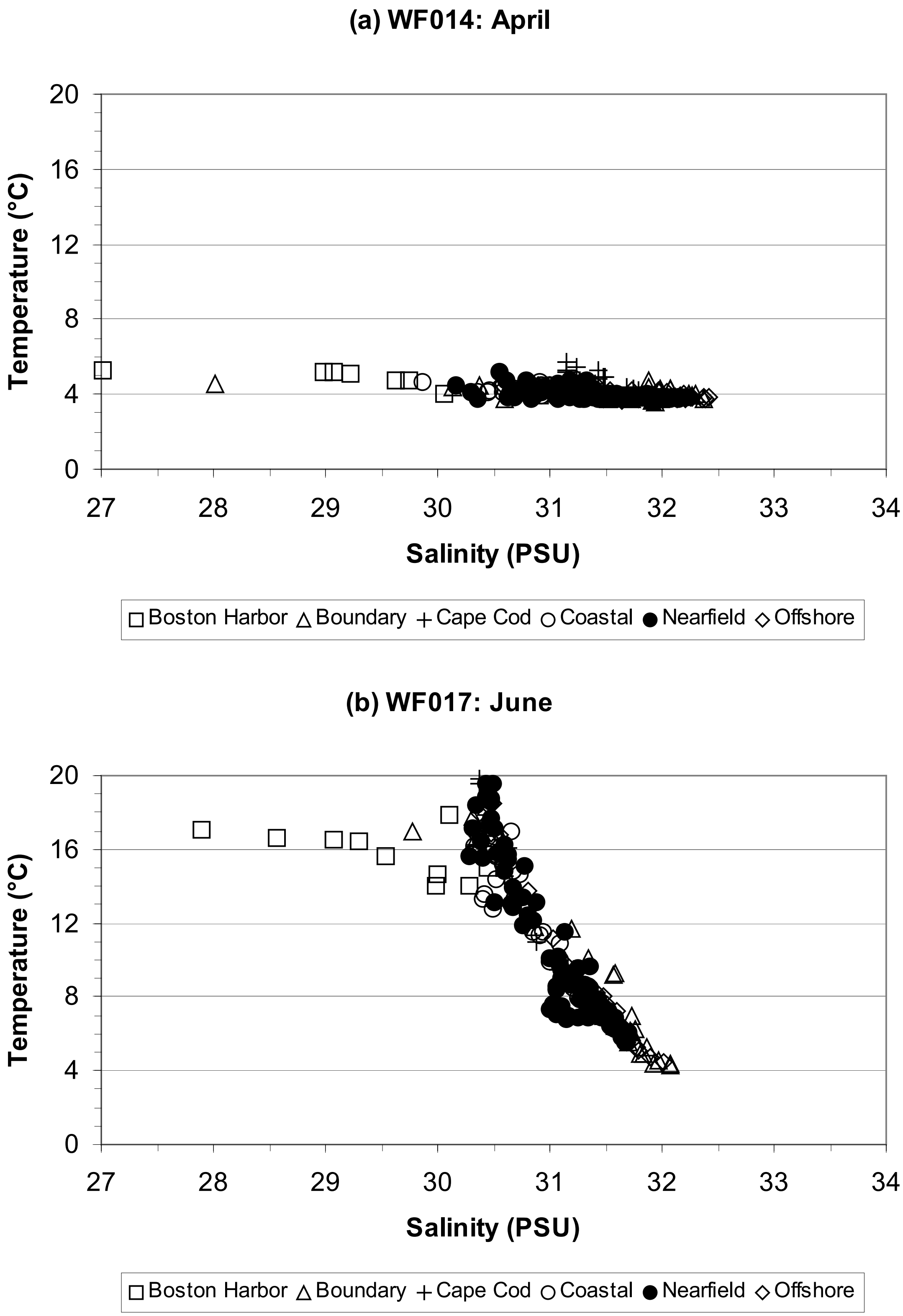


Figure 4-11. Temperature/Salinity Distribution for All Depths during WF014 (Apr 01) and WF017 (Jun 01) Surveys

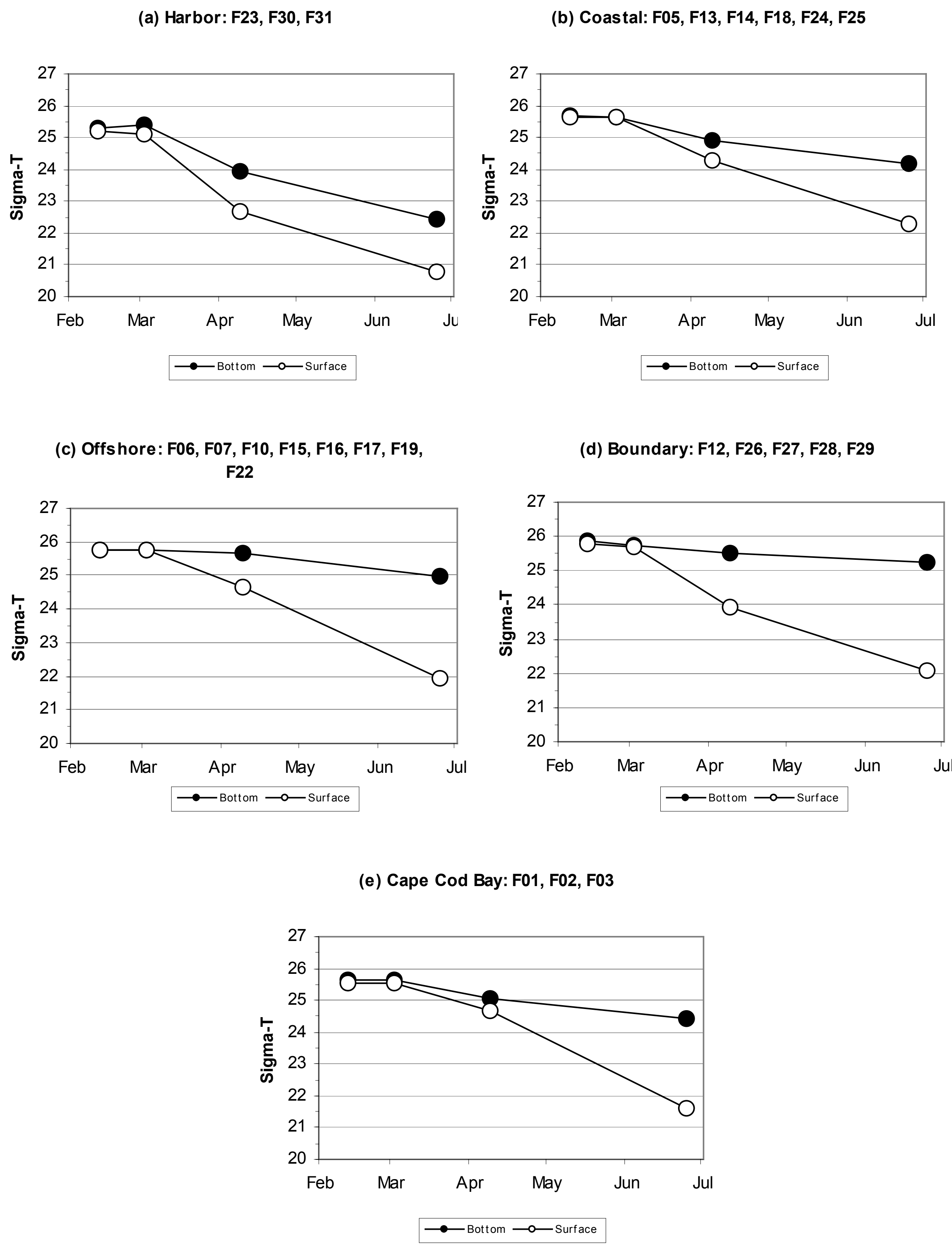


Figure 4-12. Time-Series of Average Surface and Bottom Water Density (σ_T) in the Farfield

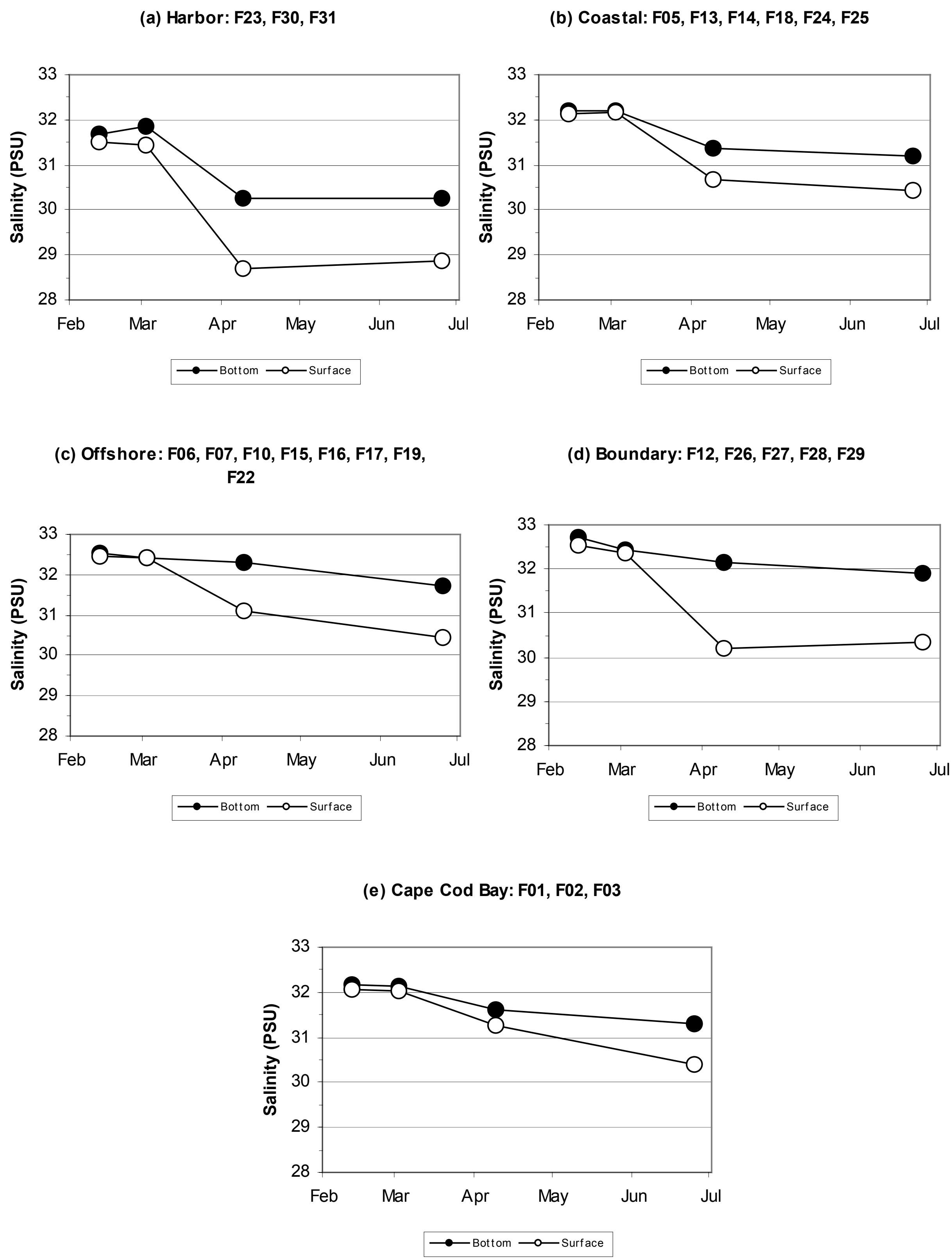


Figure 4-13. Time-Series of Average Surface and Bottom Water Salinity (PSU) in the Farfield

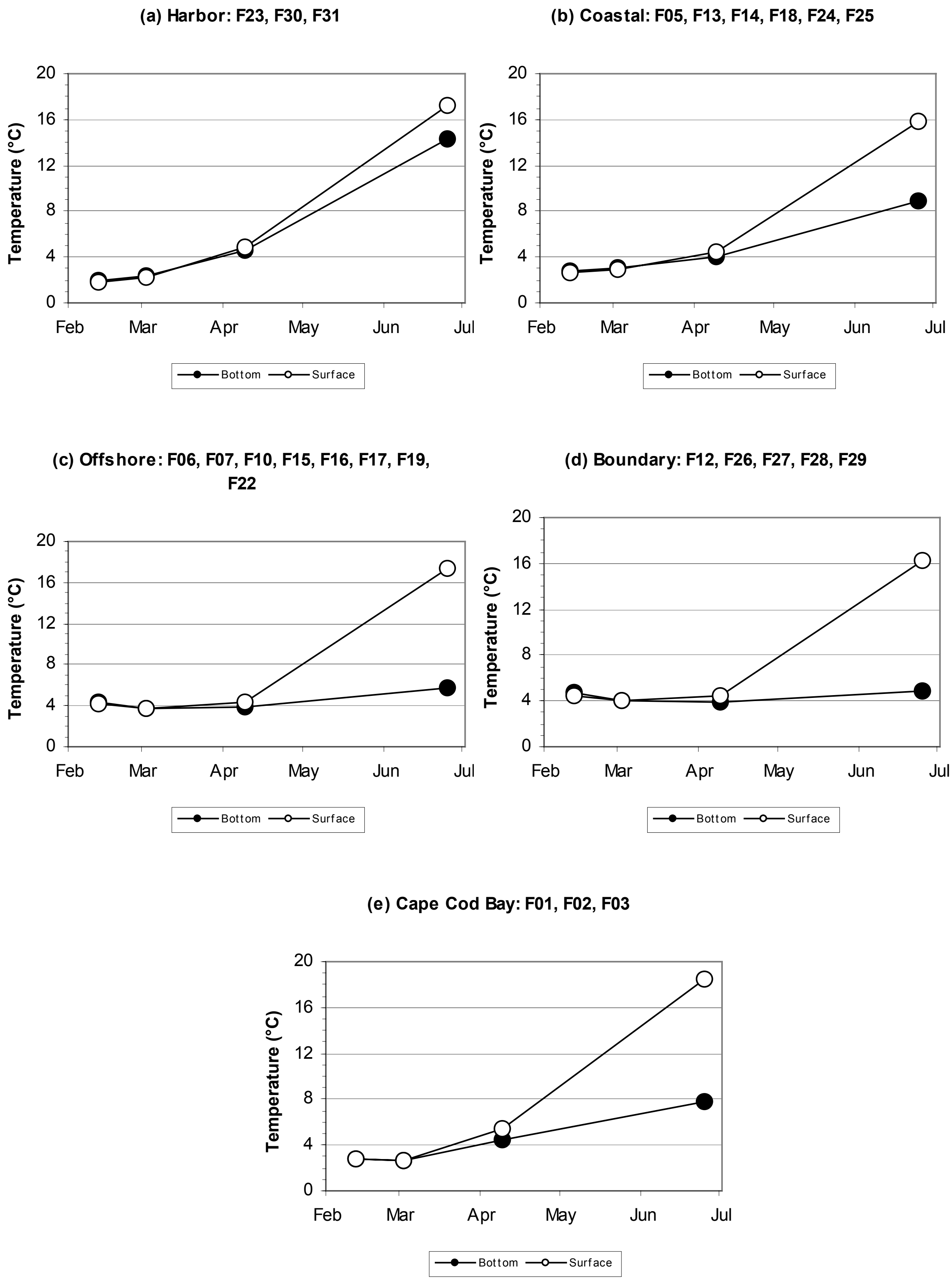


Figure 4-14. Time-Series of Average Surface and Bottom Temperature (°C) in the Farfield

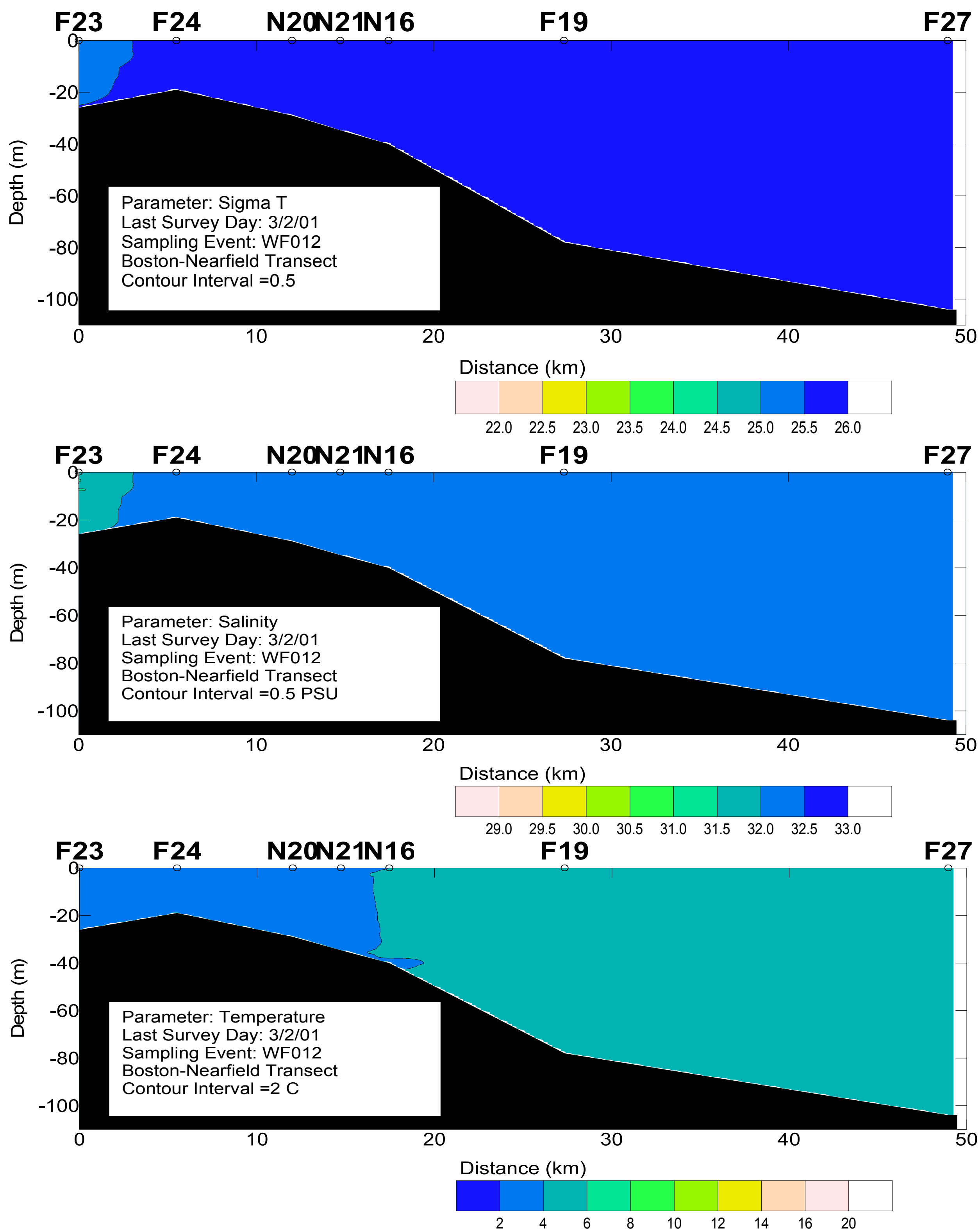


Figure 4-15. Density, Salinity, and Temperature Vertical Contour Plots along Boston-Nearfield Transect for Farfield Survey WF012 (Feb/Mar 01)

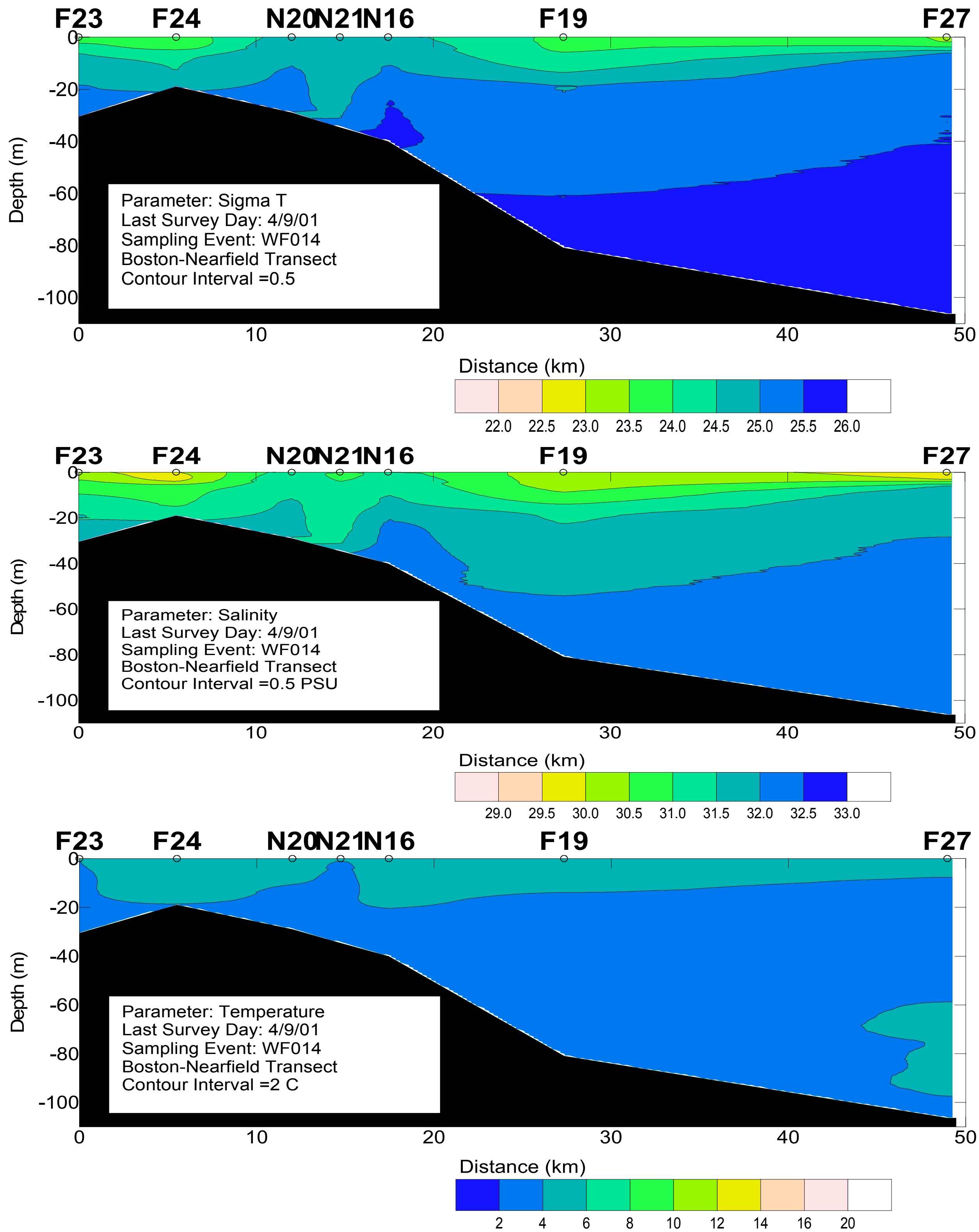


Figure 4-16. Density, Salinity, and Temperature Vertical Contour Plots along Boston-Nearfield Transect for Farfield Survey WF014 (Apr 01)

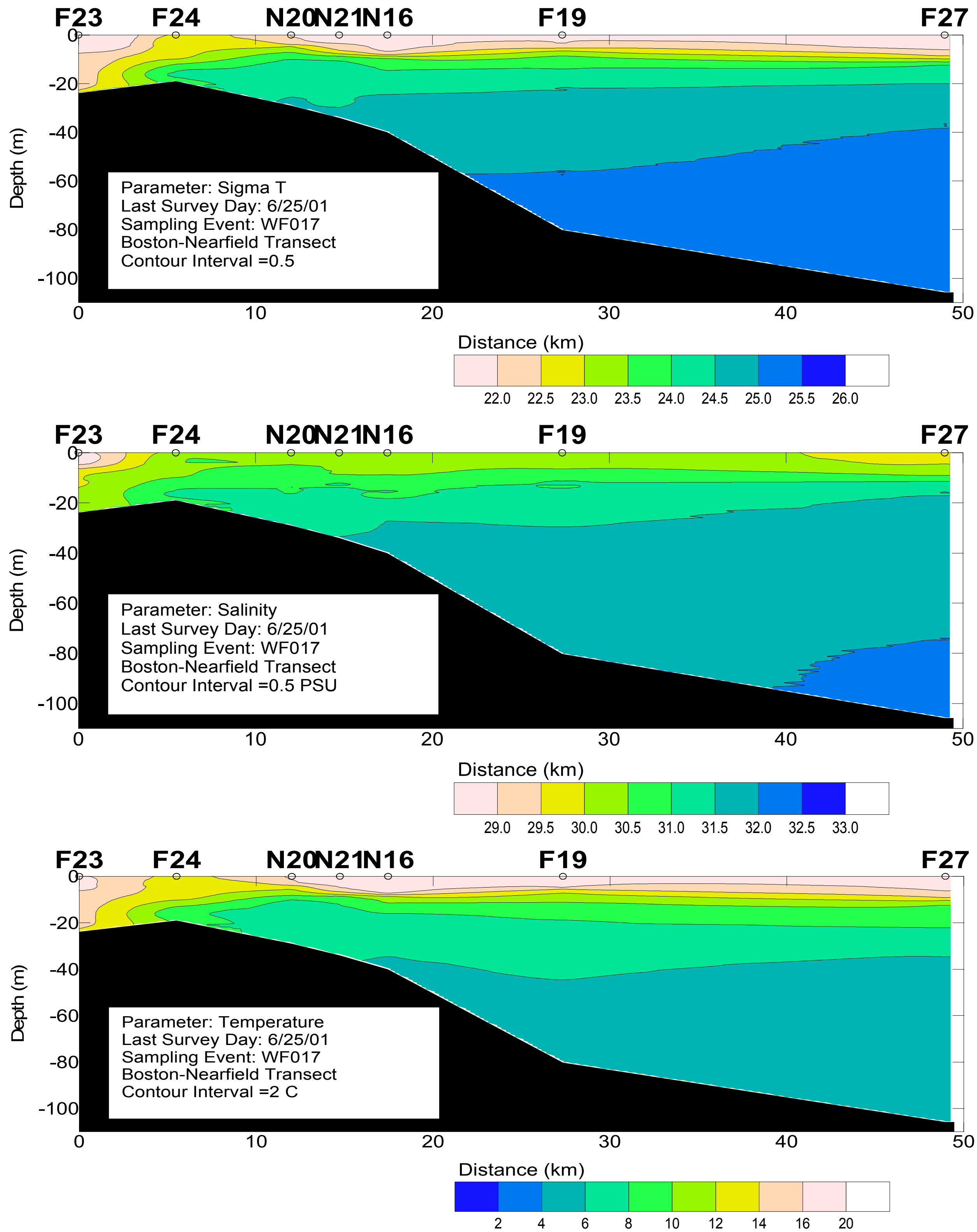


Figure 4-17. Density, Salinity, and Temperature Vertical Contour Plots along Boston-Nearfield Transect for Farfield Survey WF017 (Jun 01)

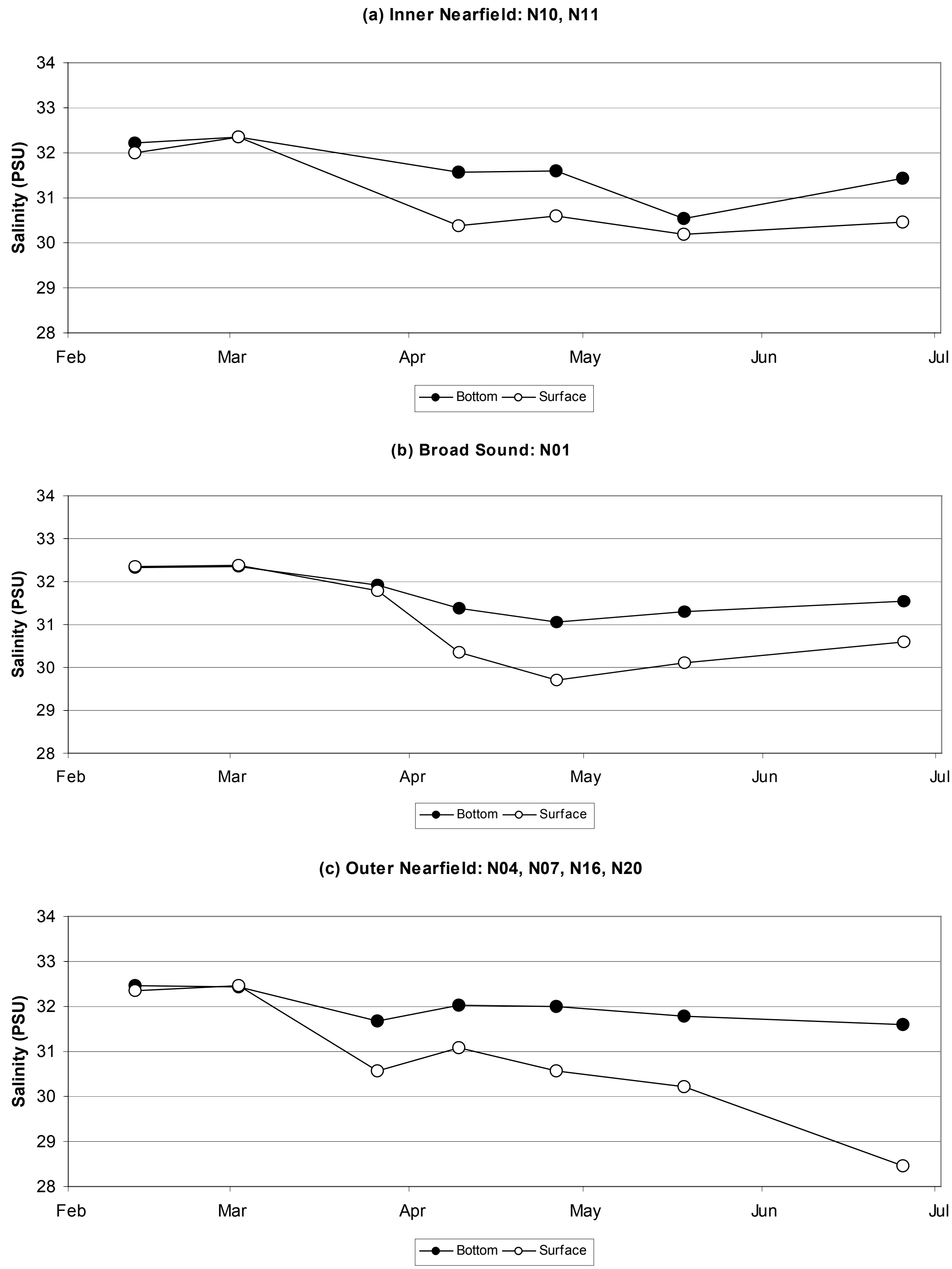


Figure 4-18. Time-Series of Average Surface and Bottom Salinity (PSU) in the Nearfield

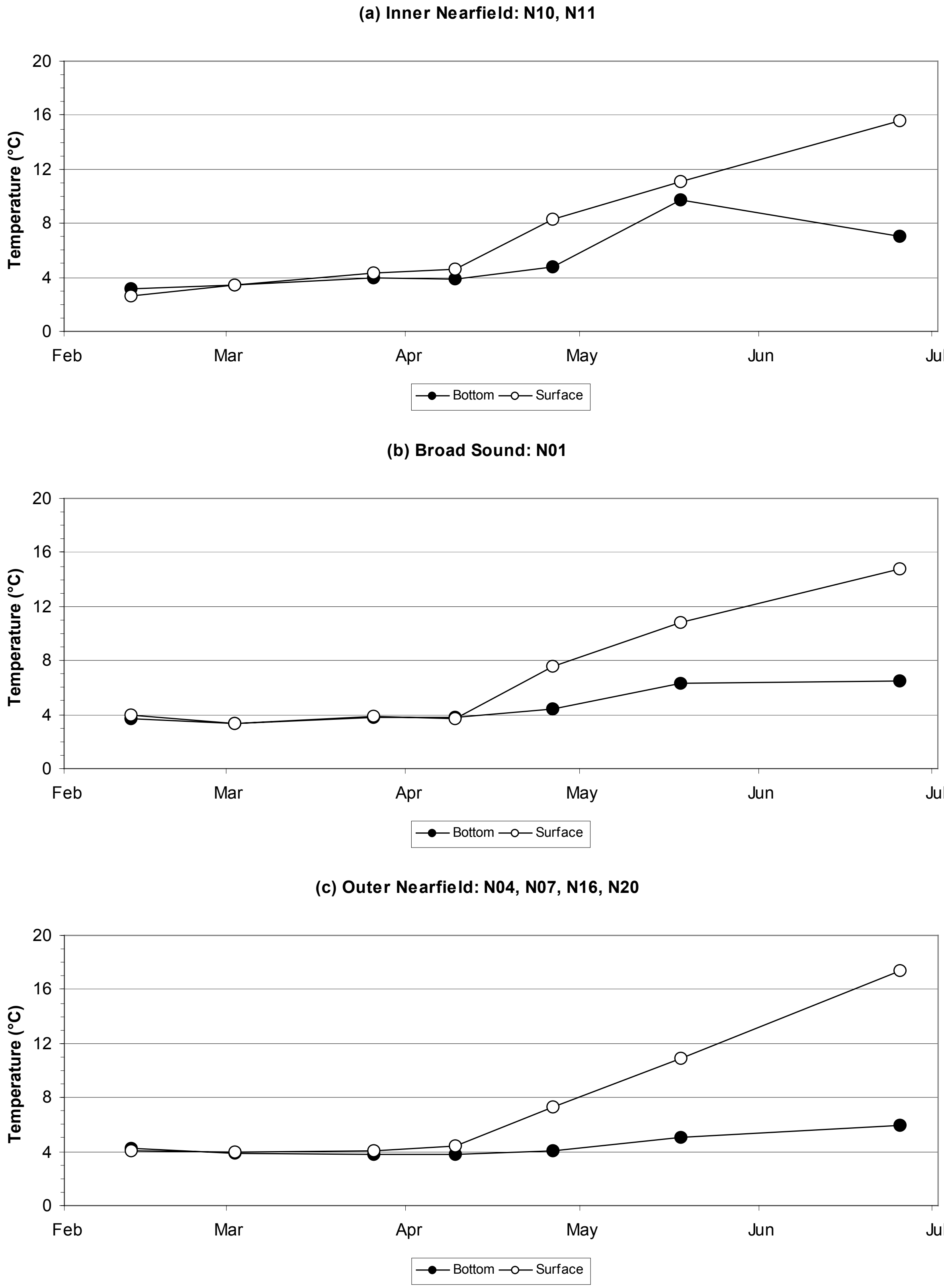


Figure 4-19. Time-Series of Average Surface and Bottom Temperature (°C) in the Nearfield

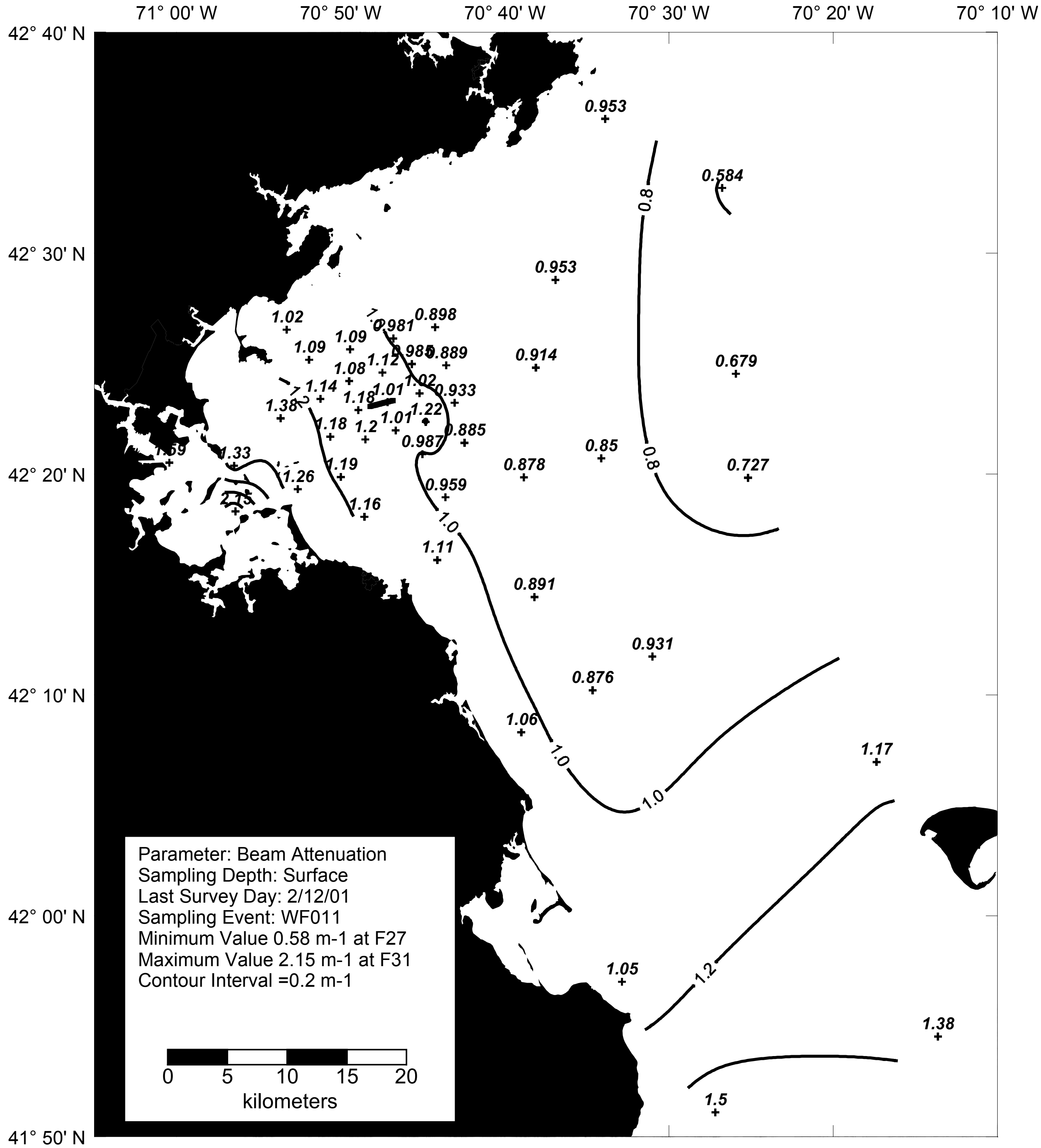


Figure 4-20. Beam Attenuation Surface Contour Plot for Farfield Survey WF011 (Feb 01)

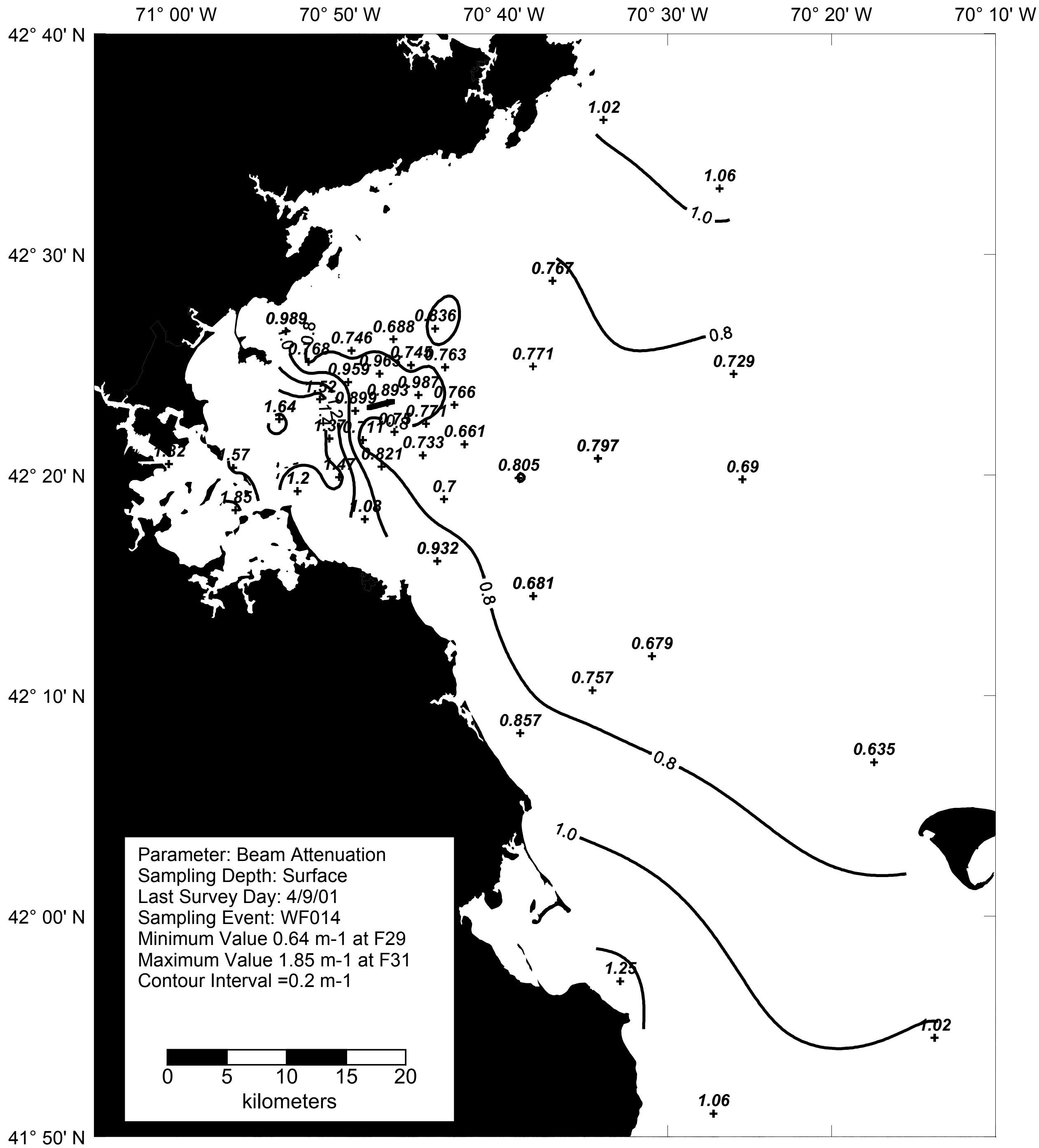


Figure 4-21. Beam Attenuation Surface Contour Plot for Farfield Survey WF014 (Apr 01)

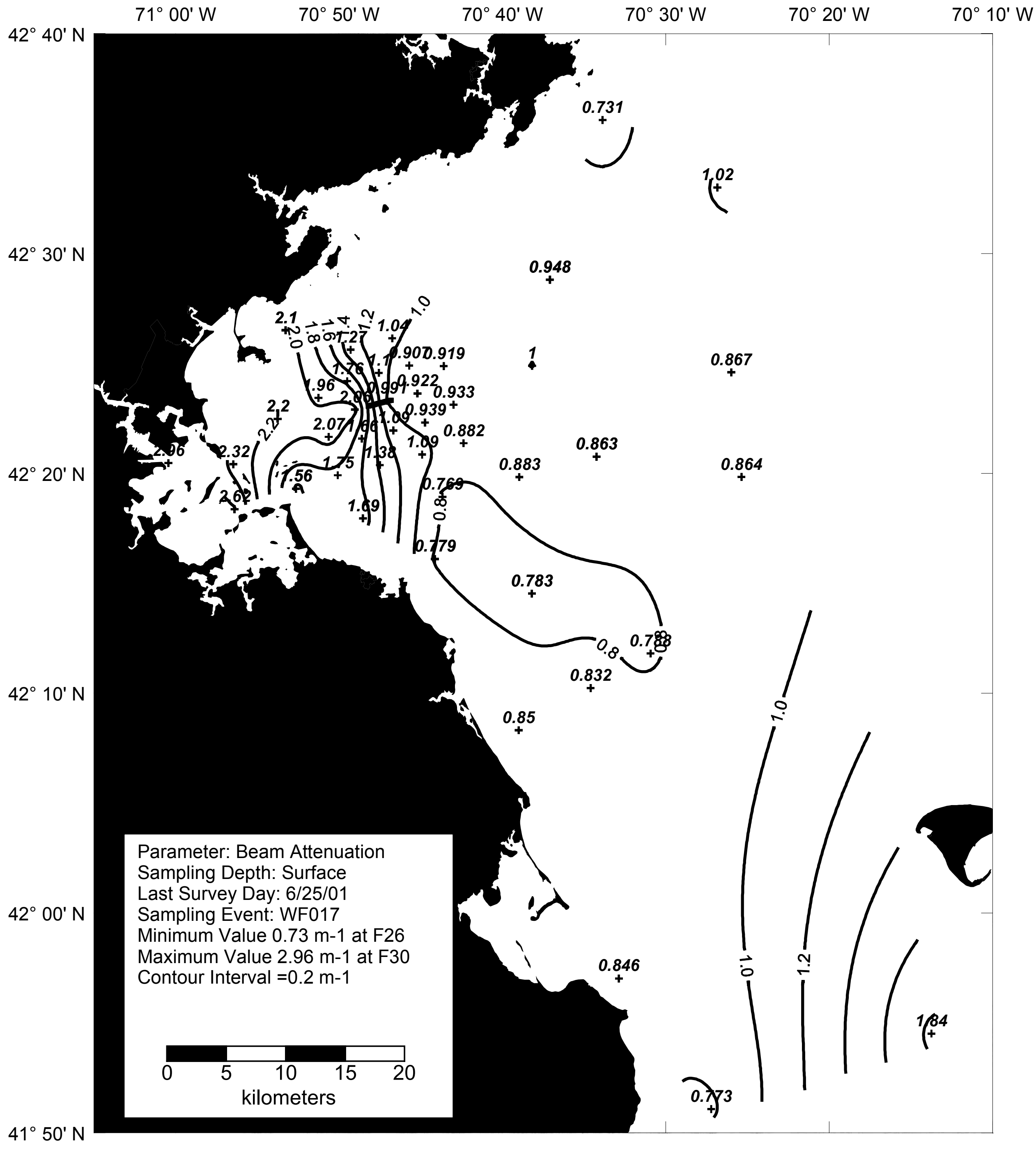


Figure 4-22. Beam Attenuation Surface Contour Plot for Farfield Survey WF017 (Jun 01)

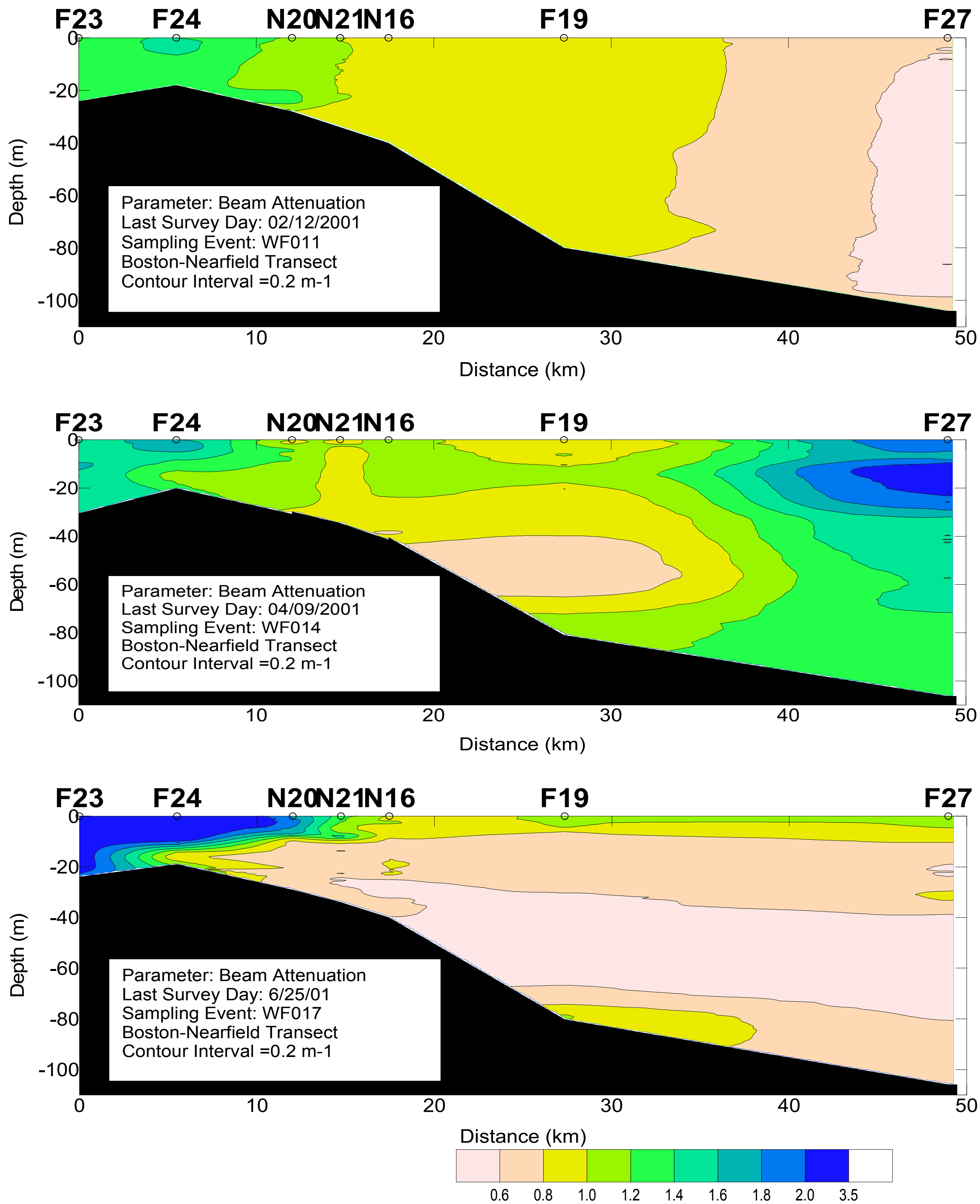


Figure 4-23. Beam Attenuation Vertical Contour Plots along the Boston-Nearfield Transect for Surveys WF011, WF014, and WF017

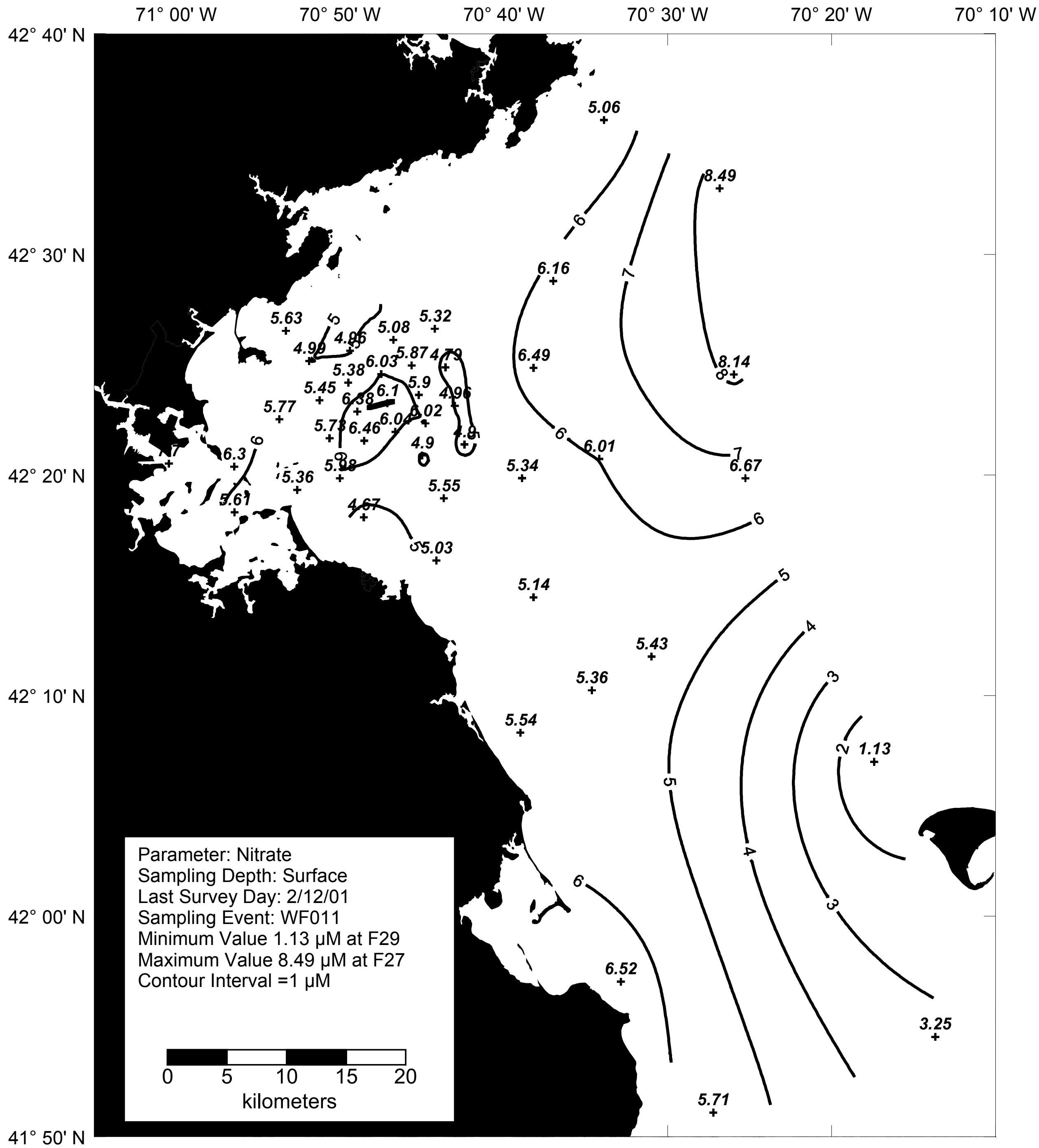


Figure 4-24. Nitrate Surface Contour Plot for Farfield Survey WF011 (Feb 01)

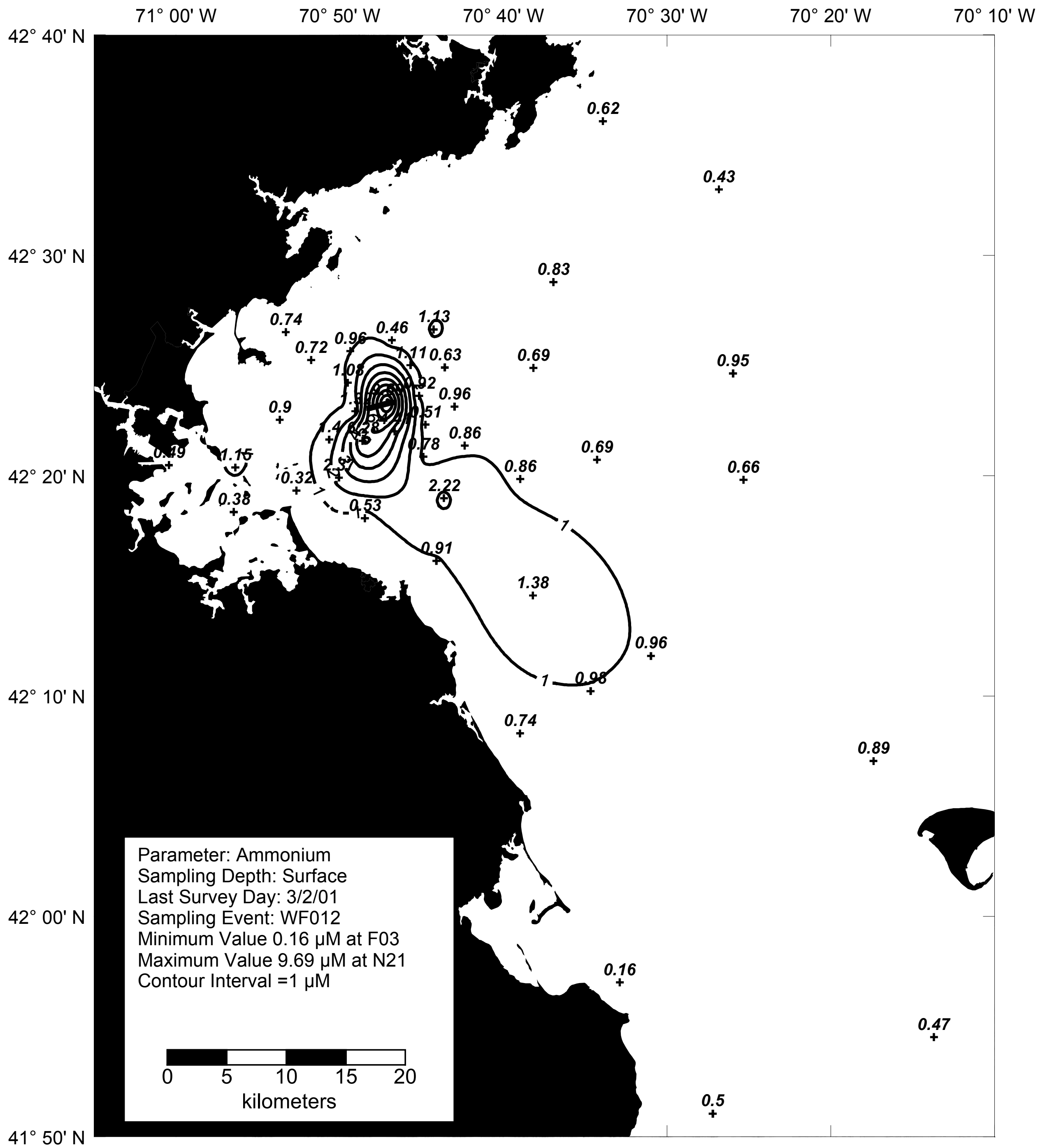


Figure 4-25. Ammonium Surface Contour Plot for Farfield Survey WF012 (Feb/Mar 01)

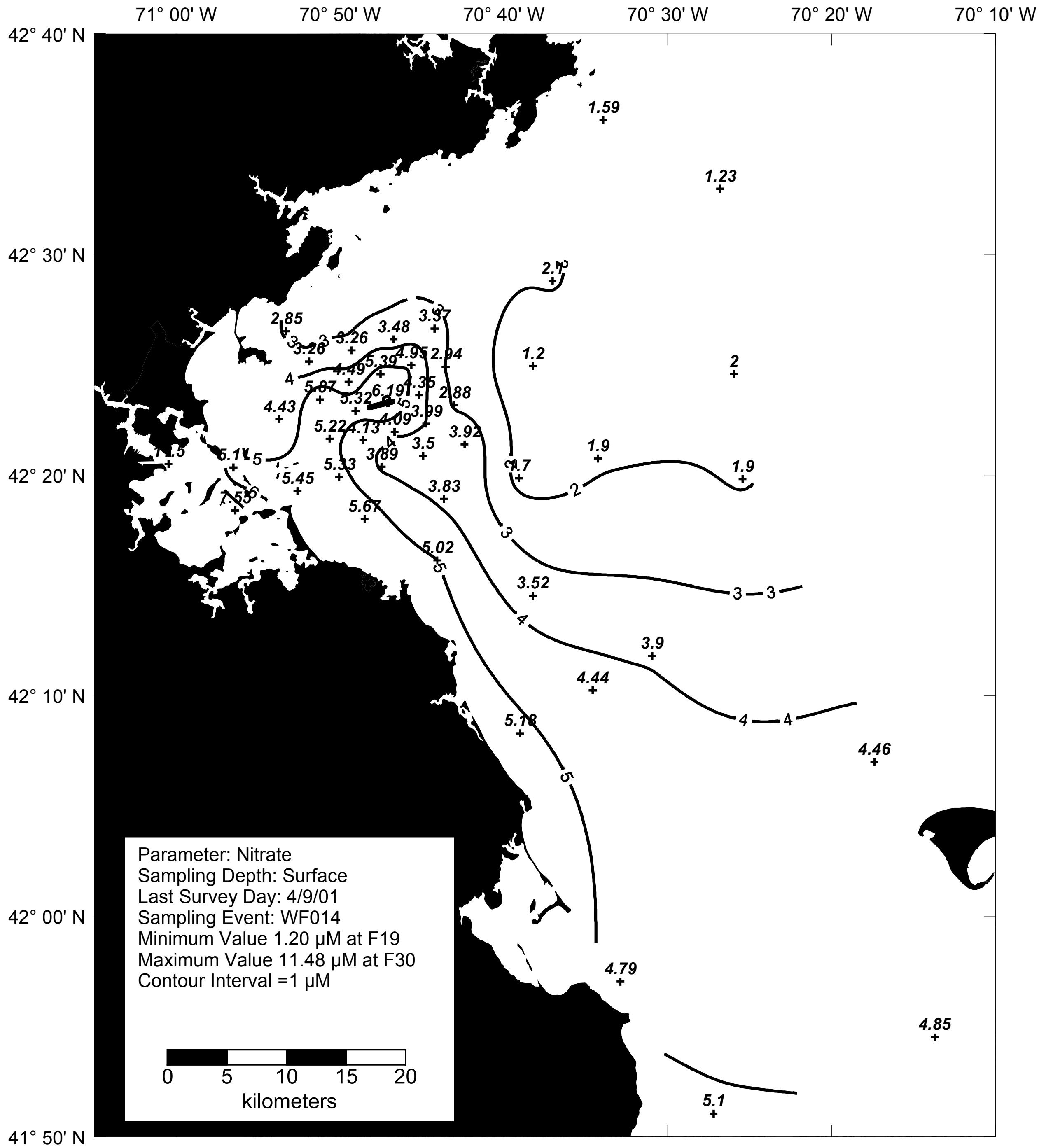


Figure 4-26. Nitrate Surface Contour Plot for Farfield Survey WF014 (Apr 01)

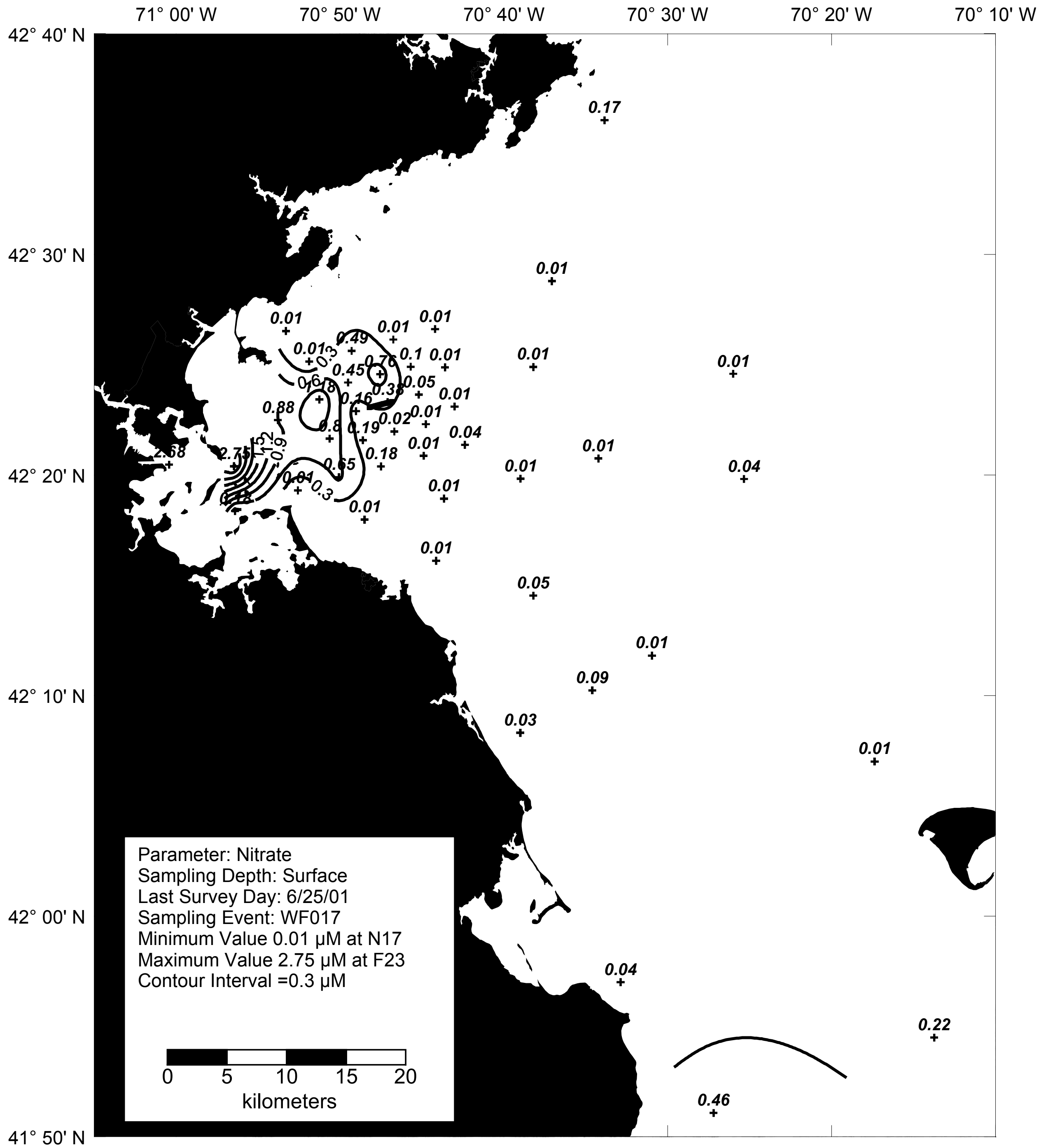


Figure 4-27. Nitrate Surface Contour Plot for Farfield Survey WF017 (Jun 01)

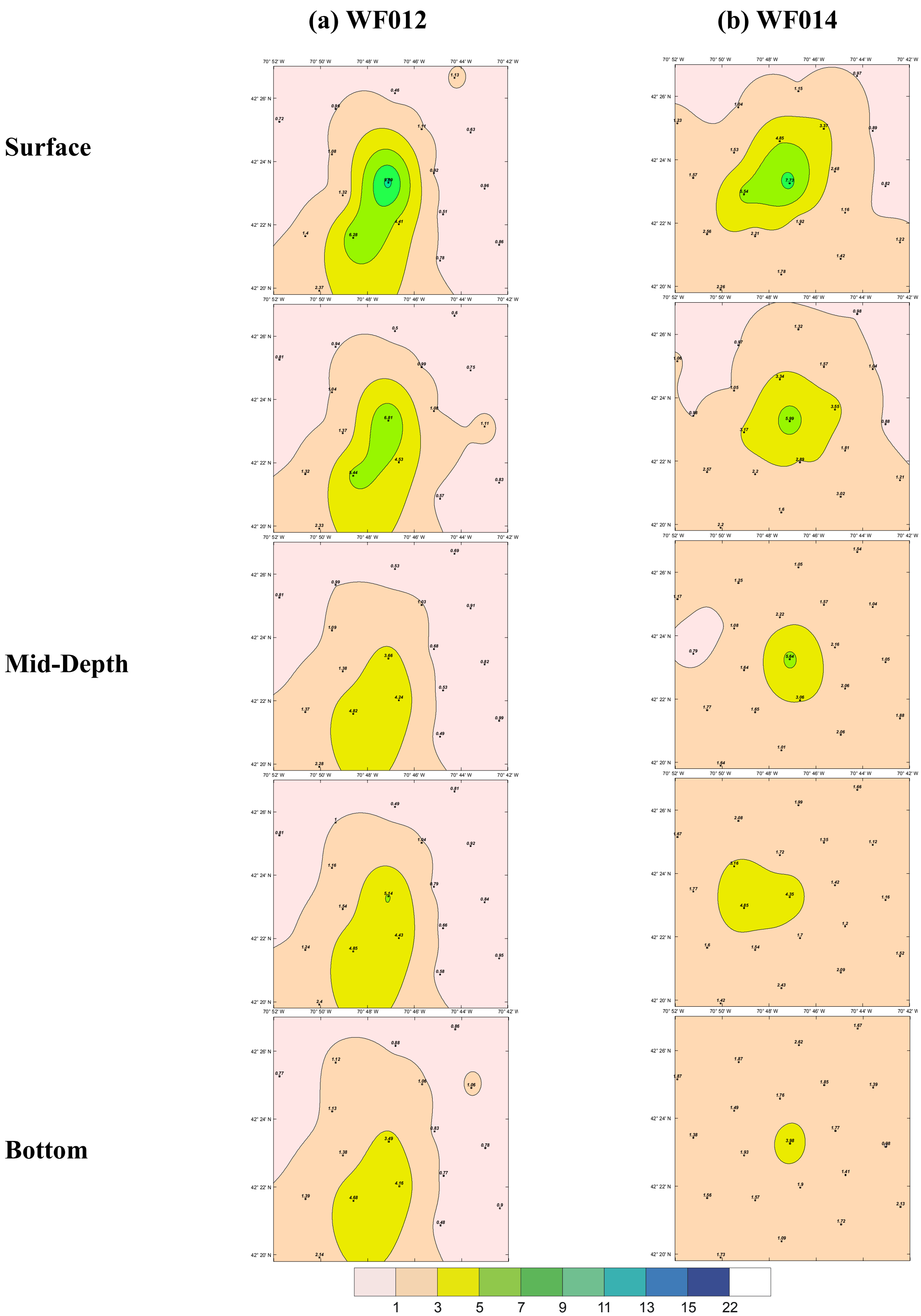


Figure 4-28. Ammonium distribution in the nearfield by depth for (a) March 1, 2001 and (b) April 4, 2001. Plots displayed from surface to bottom. Units in µM.

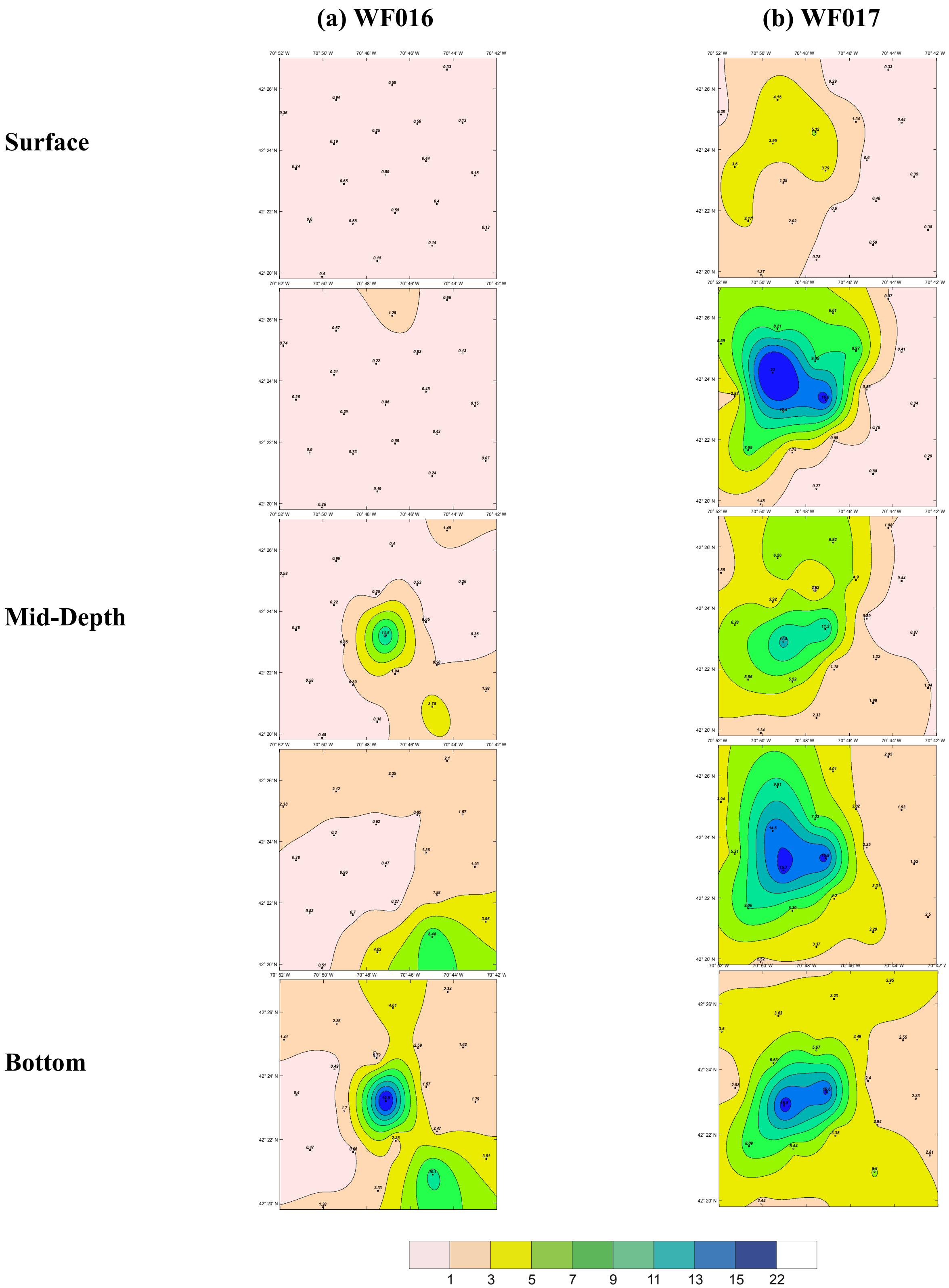
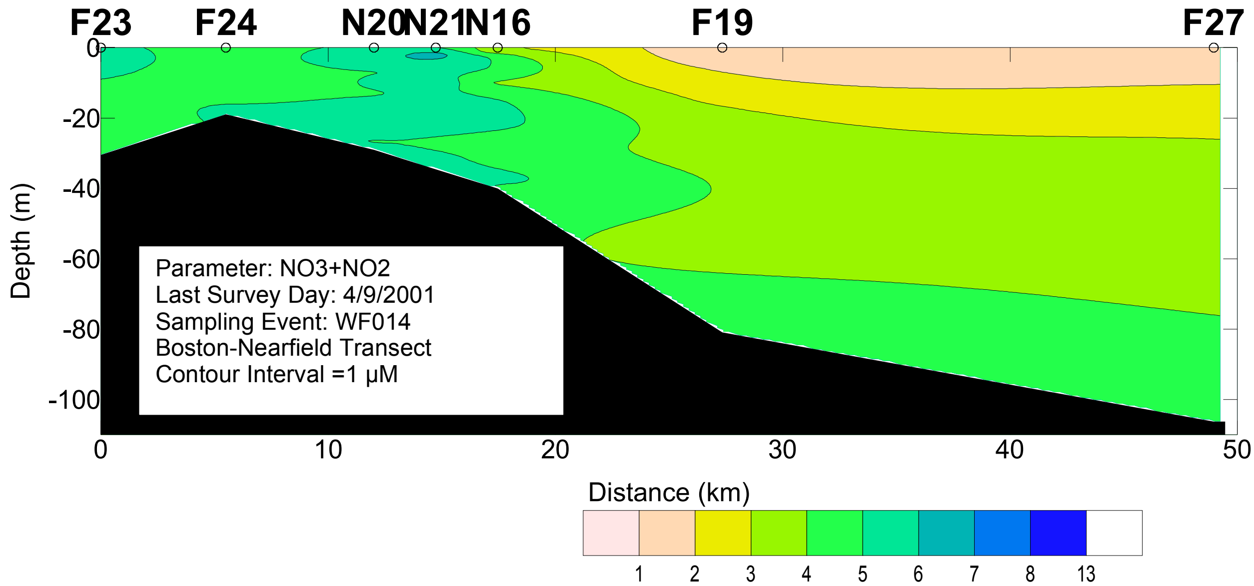


Figure 4-29. Ammonium distribution in the nearfield by depth for (a) May 18, 2001 and (b) June 25, 2001. Plots displayed from surface to bottom. Units in μM.



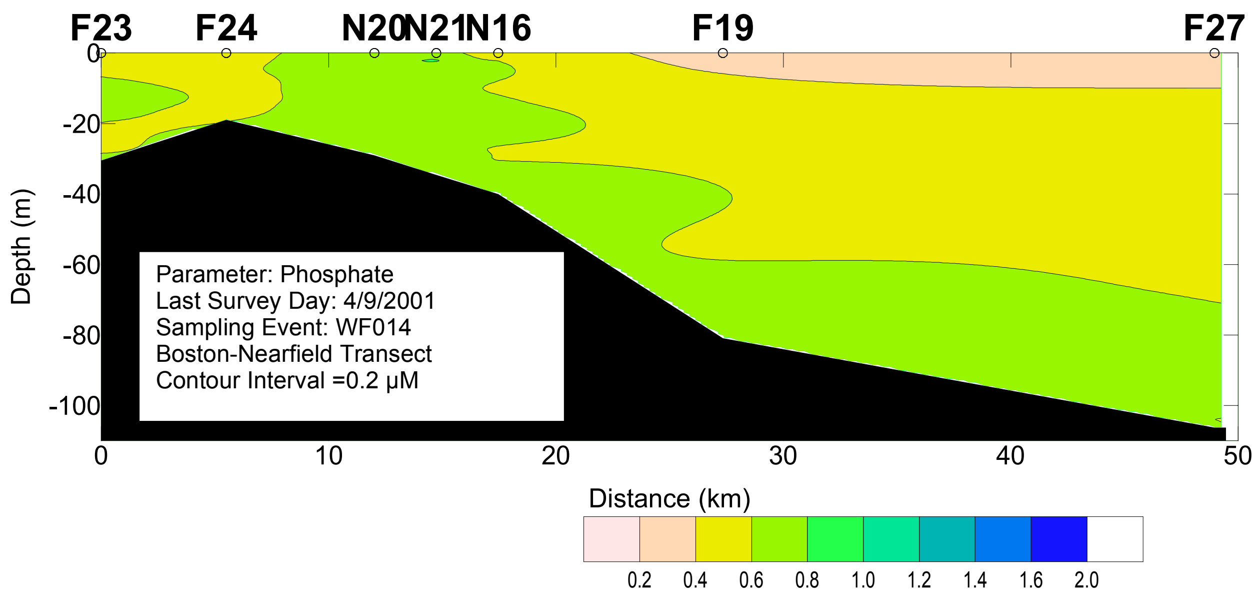
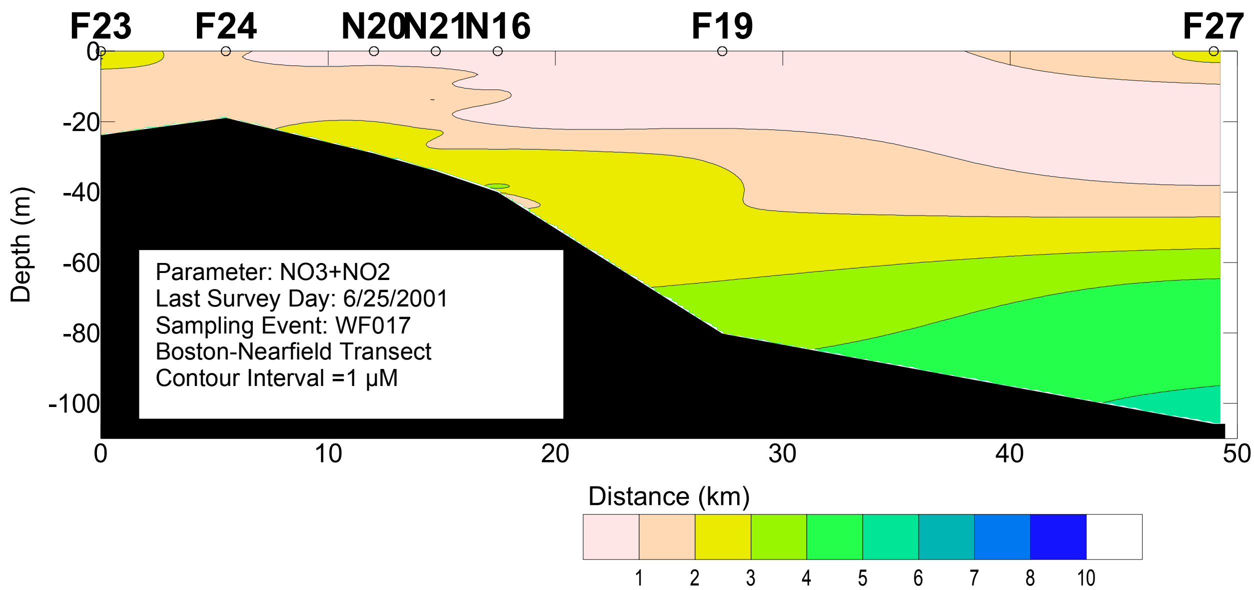


Figure 4-30. Nitrate Plus Nitrite and Phosphate Vertical Contour Plots along the Boston-Nearfield Transect for Farfield Survey WF014 (Apr 01)



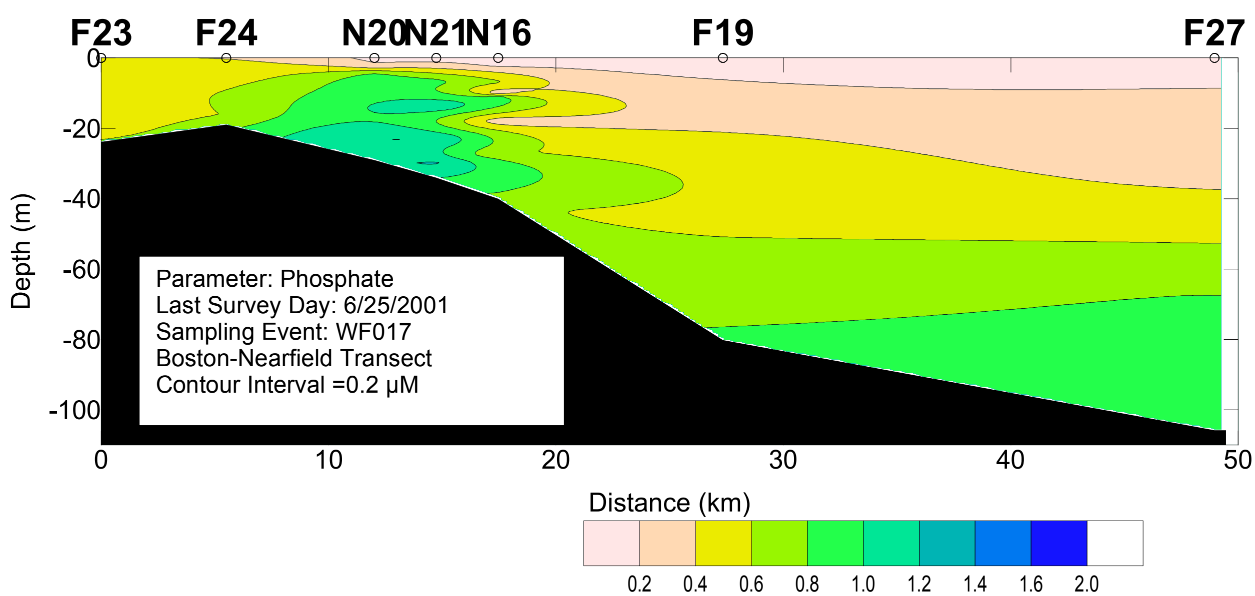


Figure 4-31. Nitrate Plus Nitrite and Phosphate Vertical Contour Plots along the Boston-Nearfield Transect for Farfield Survey WF017 (Jun 01)

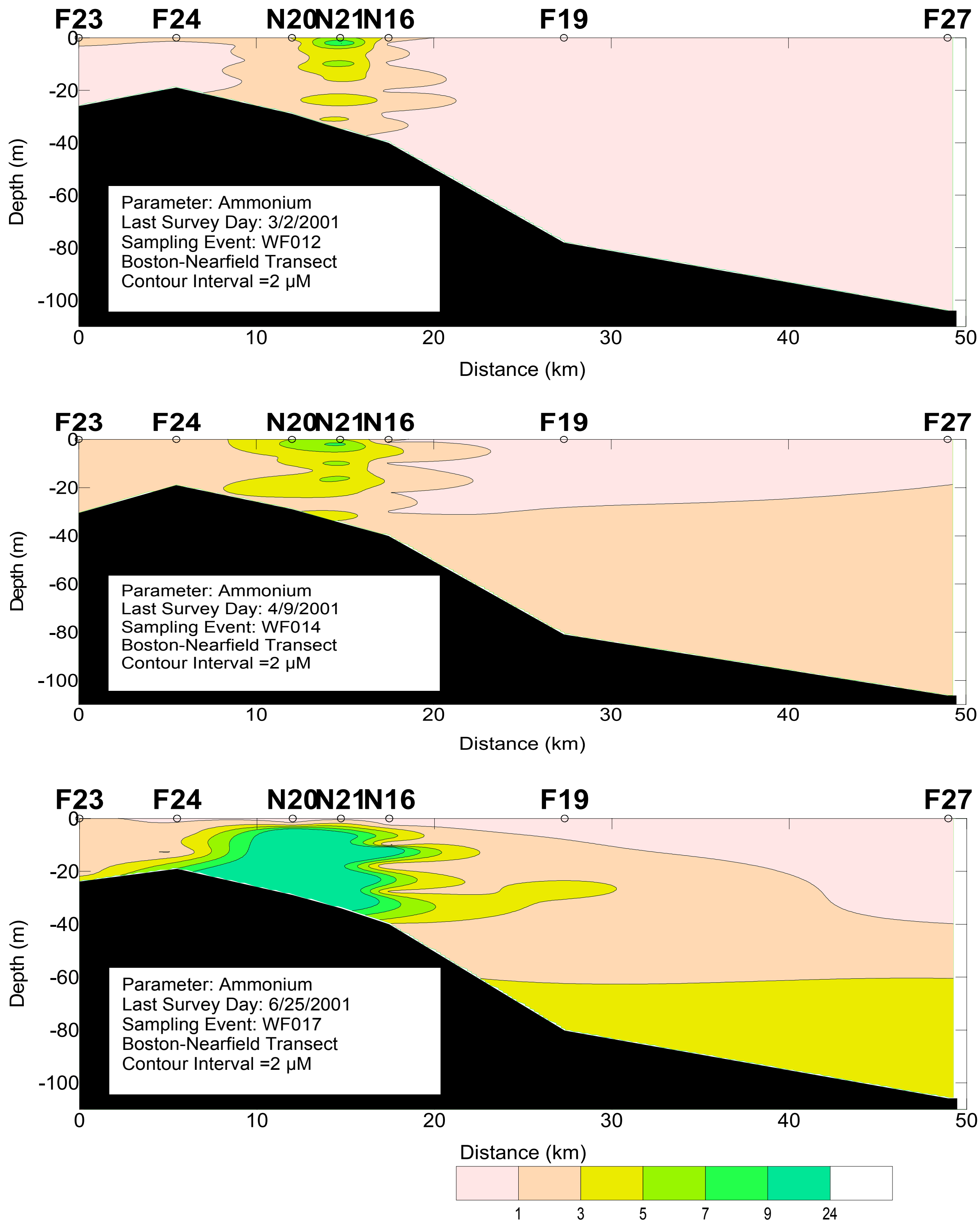
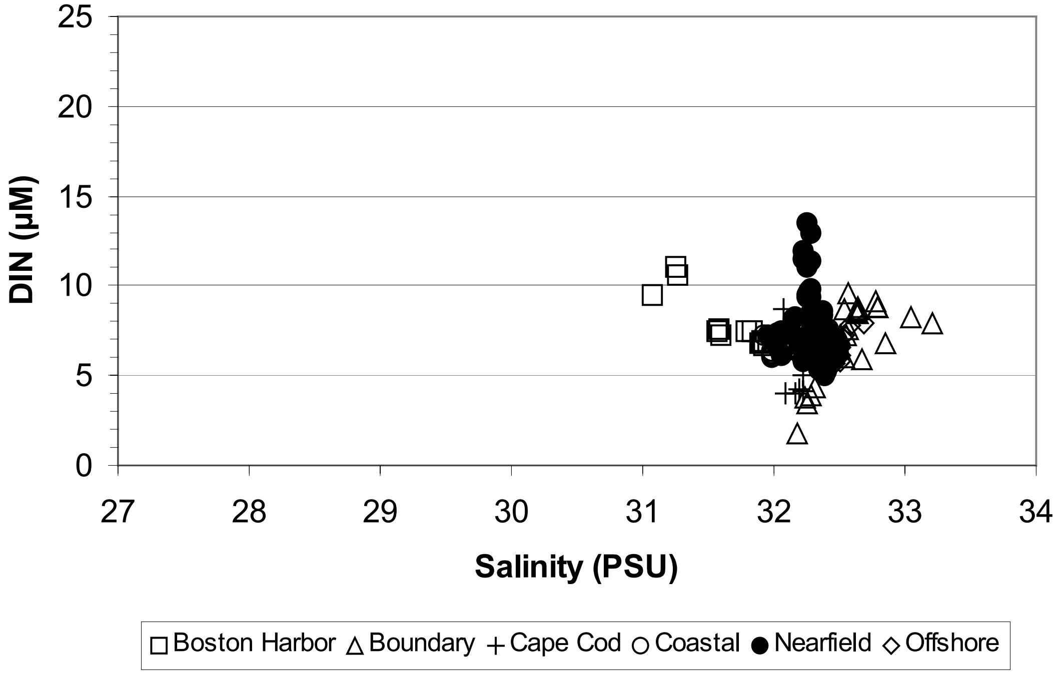


Figure 4-32. Ammonium Vertical Contour Plots along the Boston-Nearfield Transect for Farfield Surveys WF012, WF014, and WF017

(a) WF011



(b) WF012

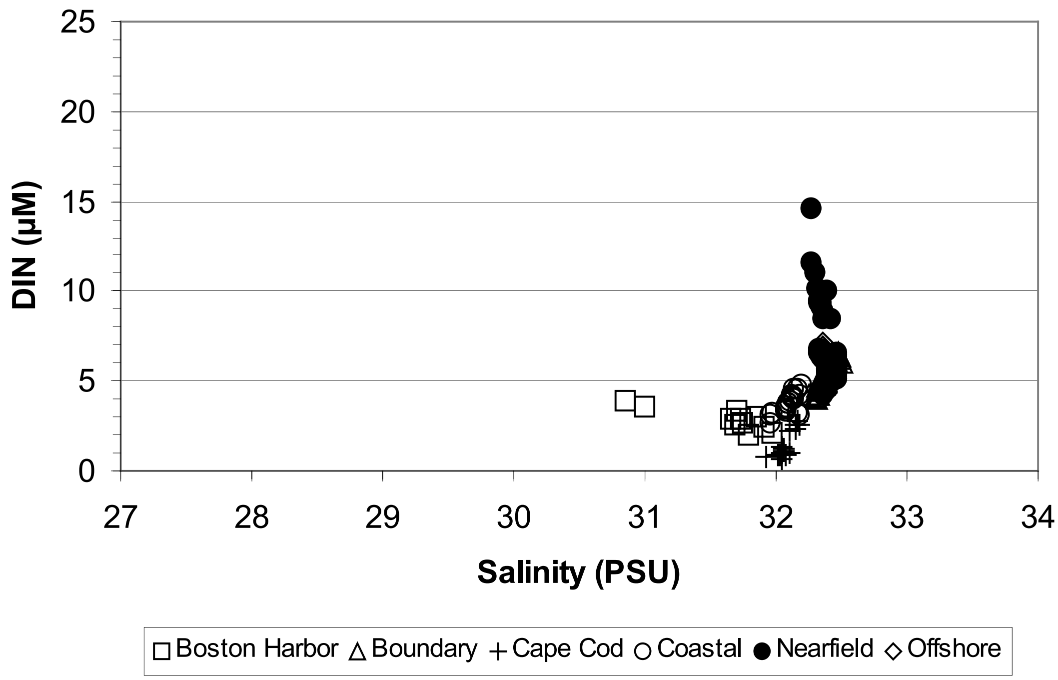


Figure 4-33. DIN vs. Salinity for All Depths during Farfield Surveys WF011 (Feb 01) and WF012 (Feb/Mar 01)

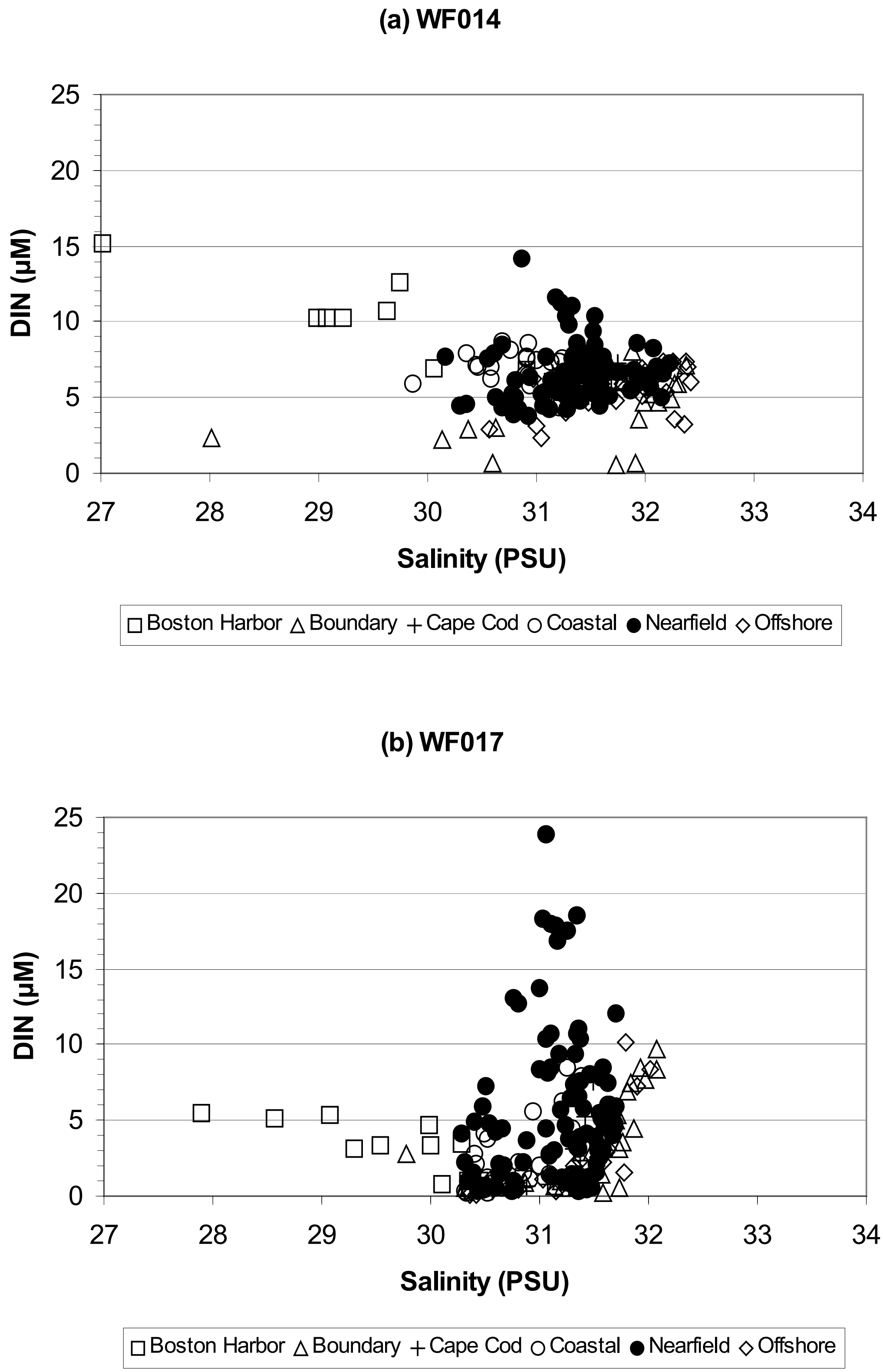


Figure 4-34. DIN vs. Salinity for All Depths during Farfield Surveys WF014 (Apr 01) and WF017 (Jun 01)

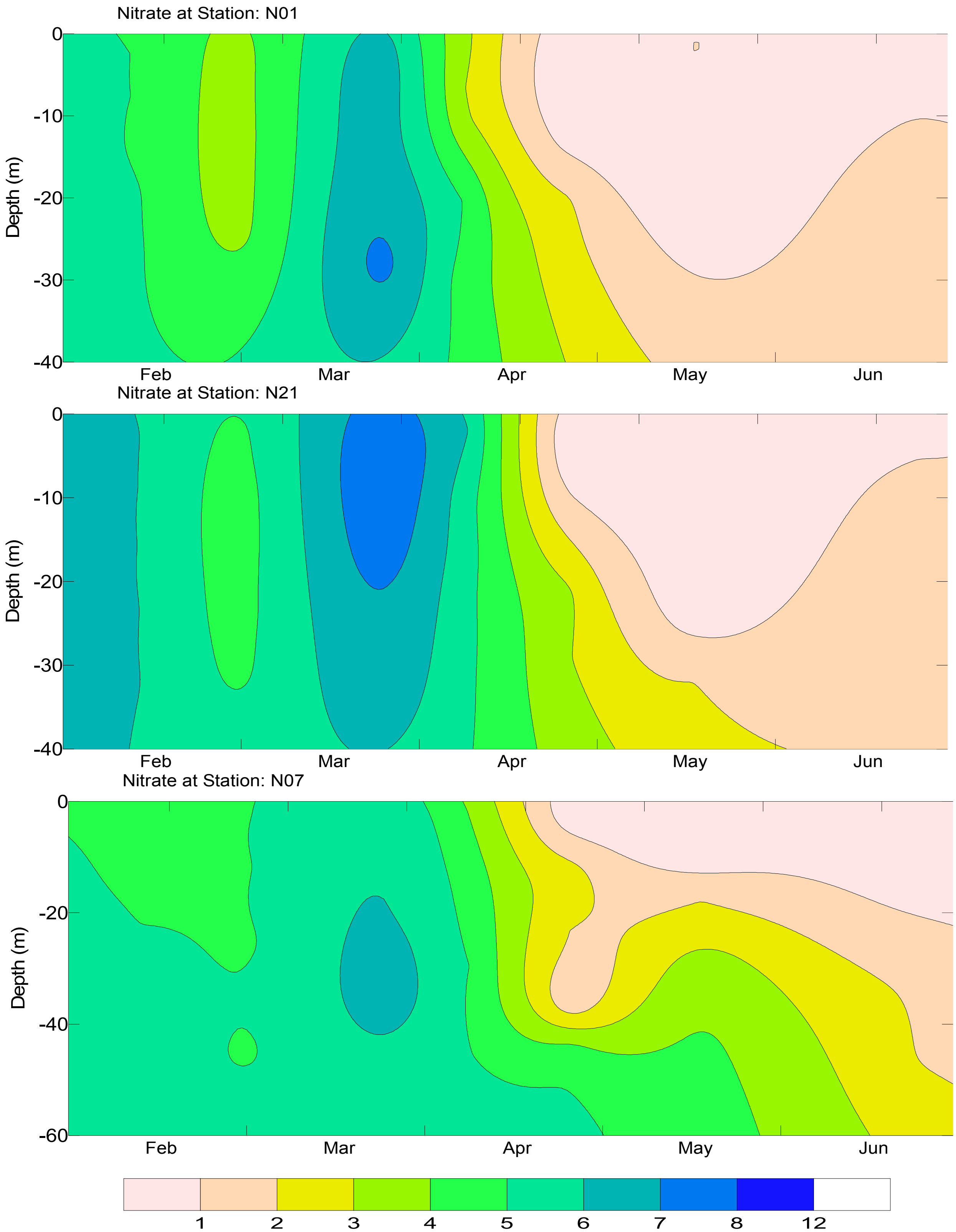


Figure 4-35. Nearfield Depth vs. Time Contour Plots of Nitrate for Stations N01, N21, and N07

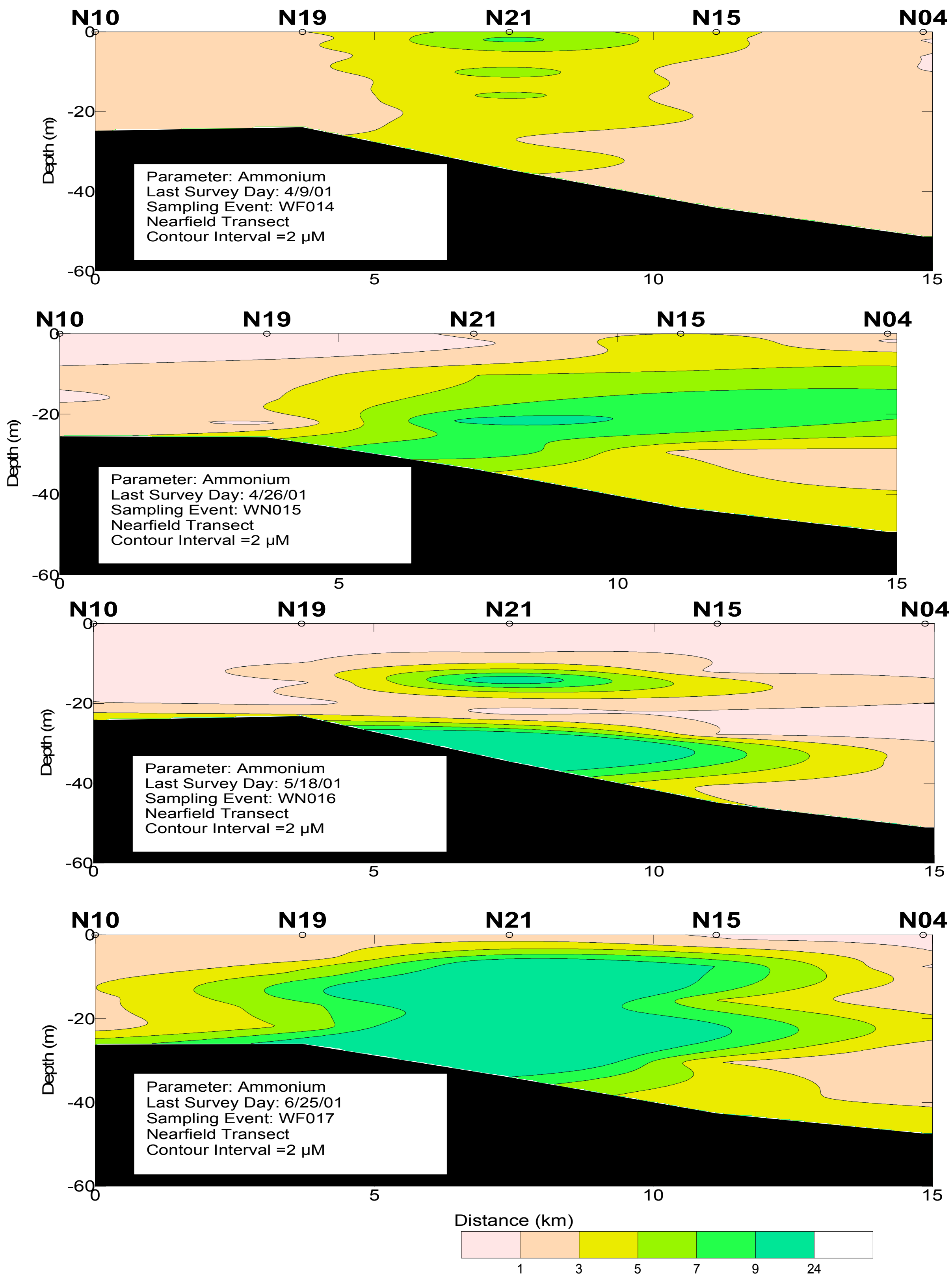


Figure 4-36. Ammonium Vertical Contour Plots along the Nearfield Transect for Surveys WF014, WN015, WN016, and WF017

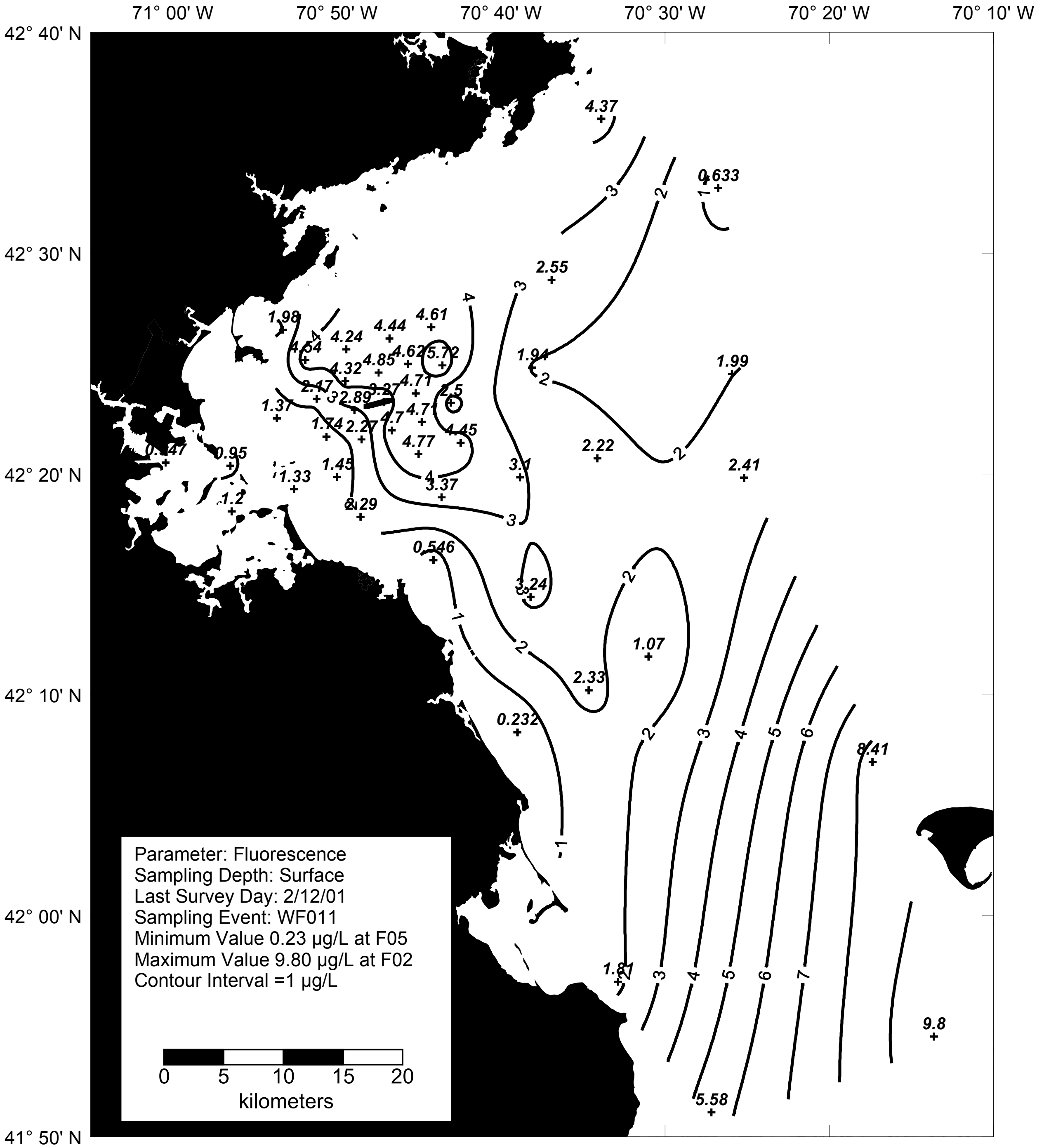


Figure 4-37. Fluorescence Surface Contour Plot for Farfield Survey WF011 (Feb 01)

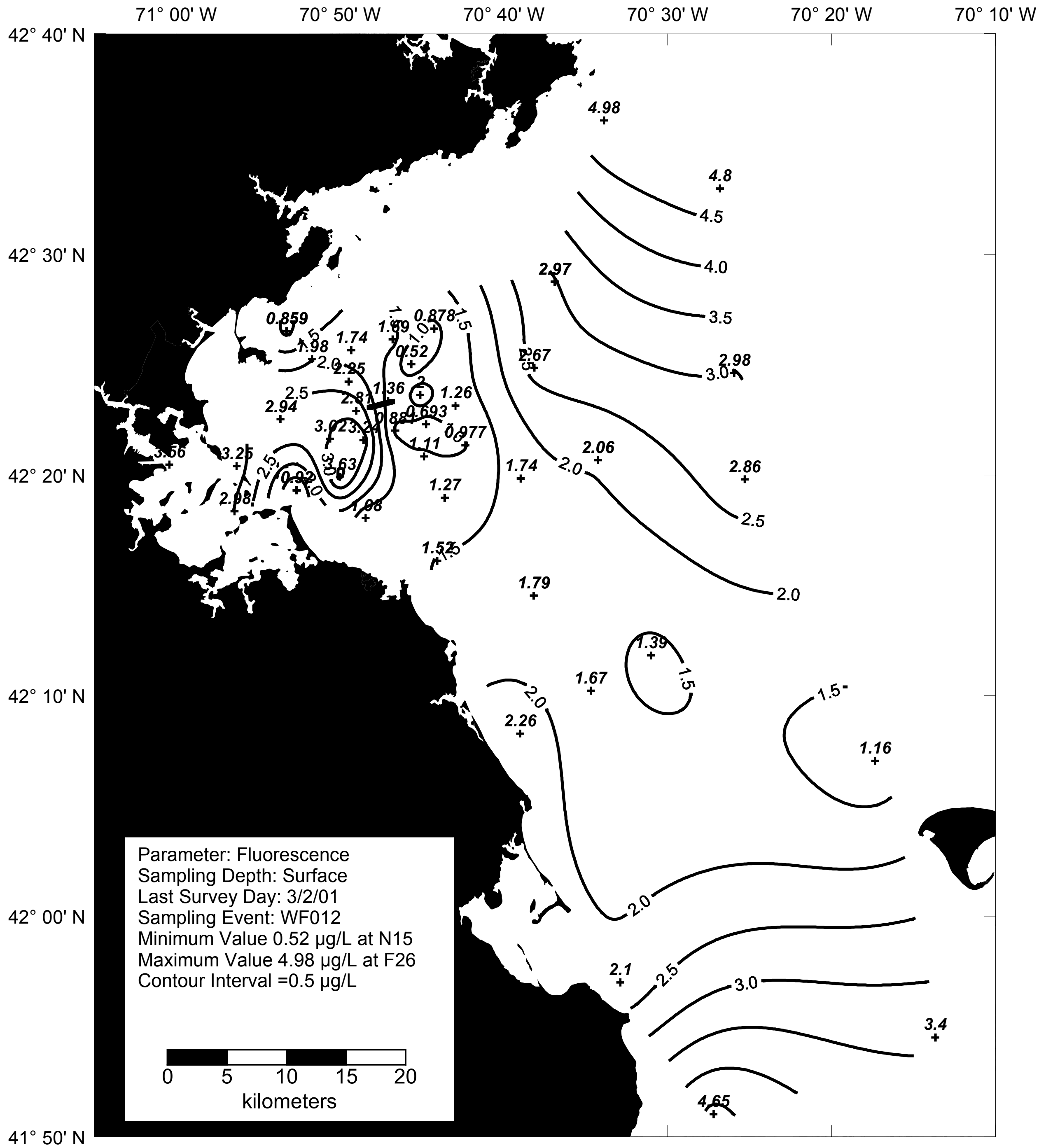


Figure 4-38. Fluorescence Surface Contour Plot for Farfield Survey WF012 (Feb/Mar 01)

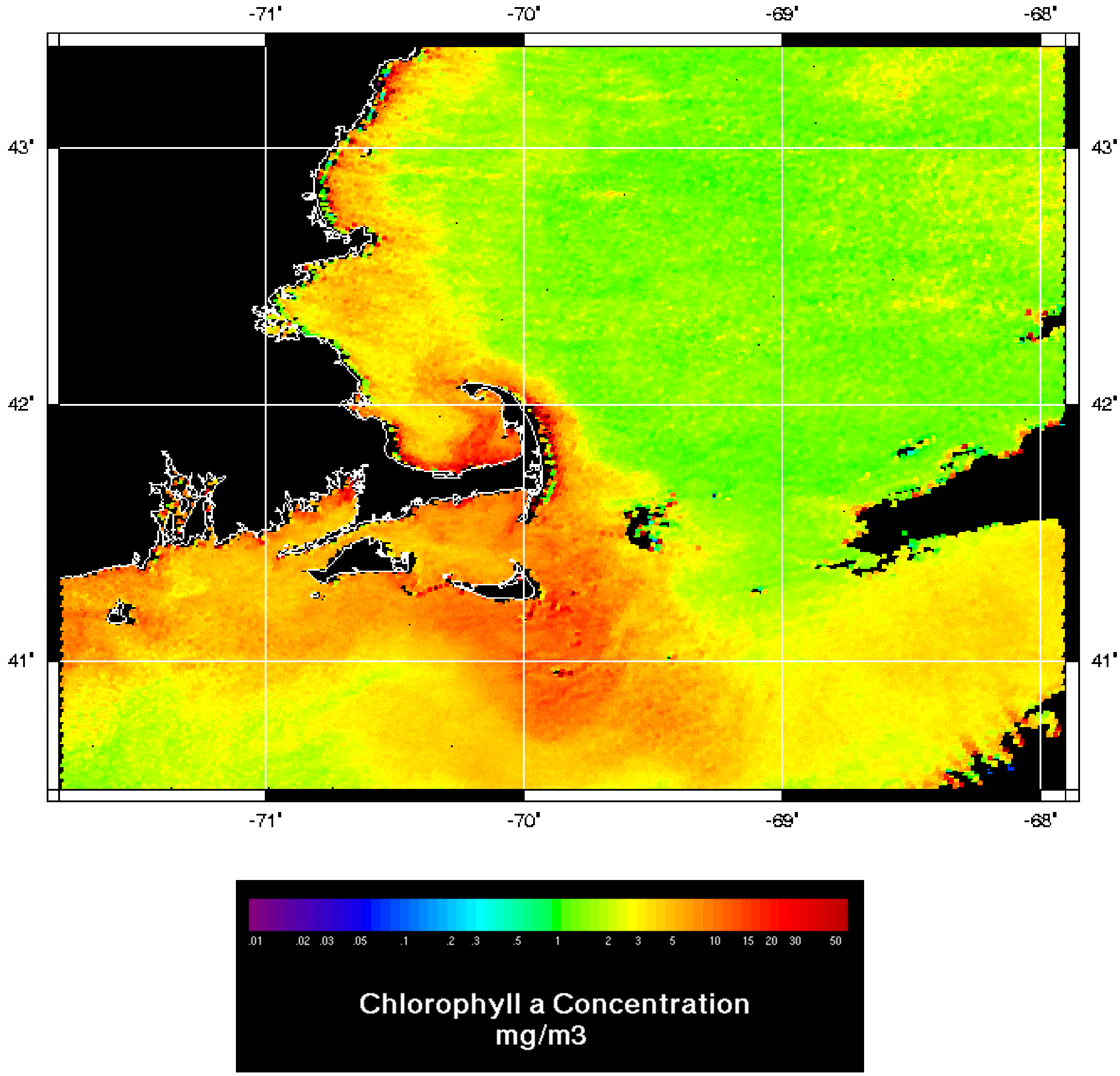


Figure 4-39. SeaWiFS Chlorophyll image for Southwestern Gulf of Maine for February 10, 2001

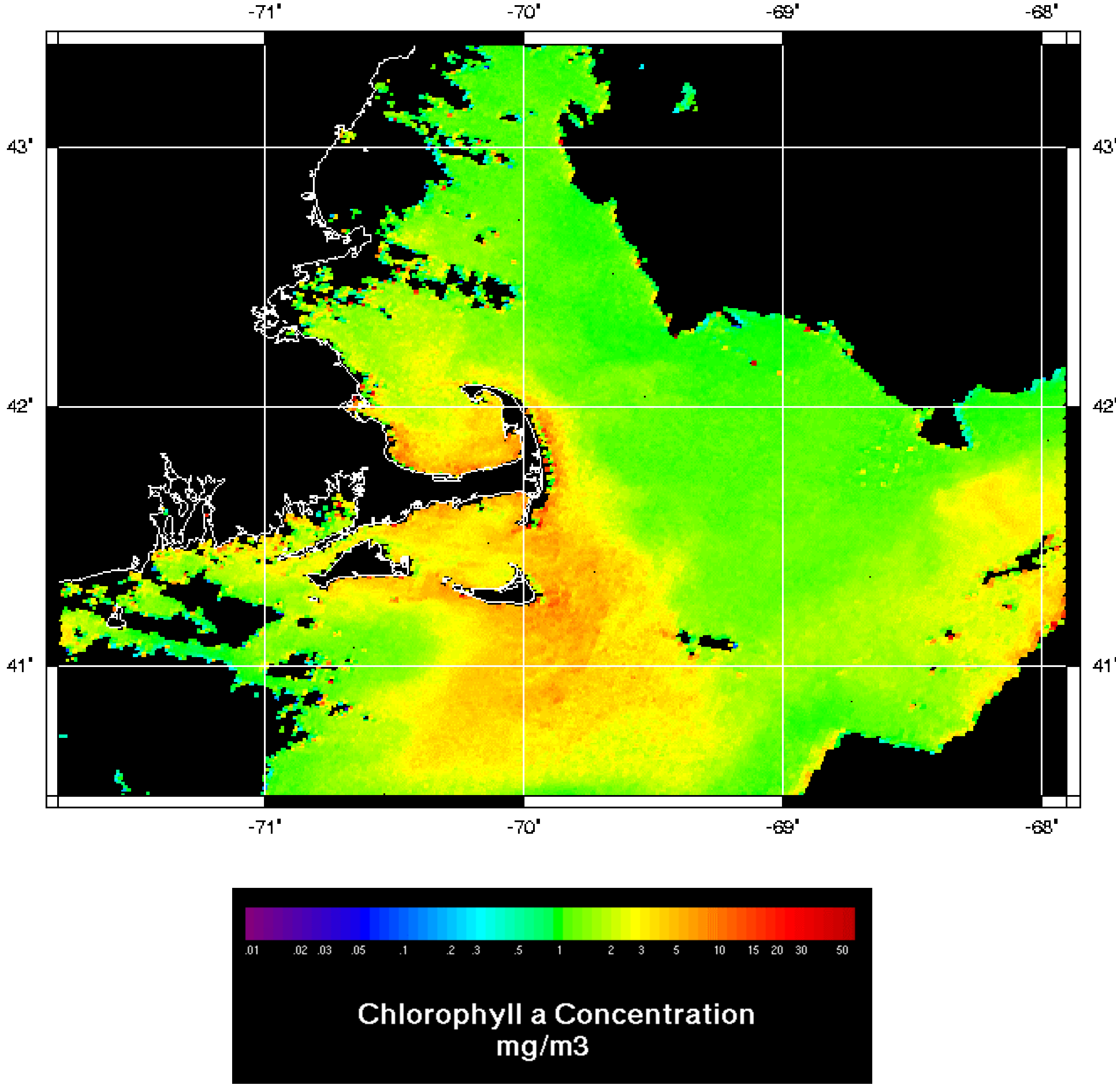


Figure 4-40. SeaWiFS Chlorophyll image for Southwestern Gulf of Maine for February 26, 2001

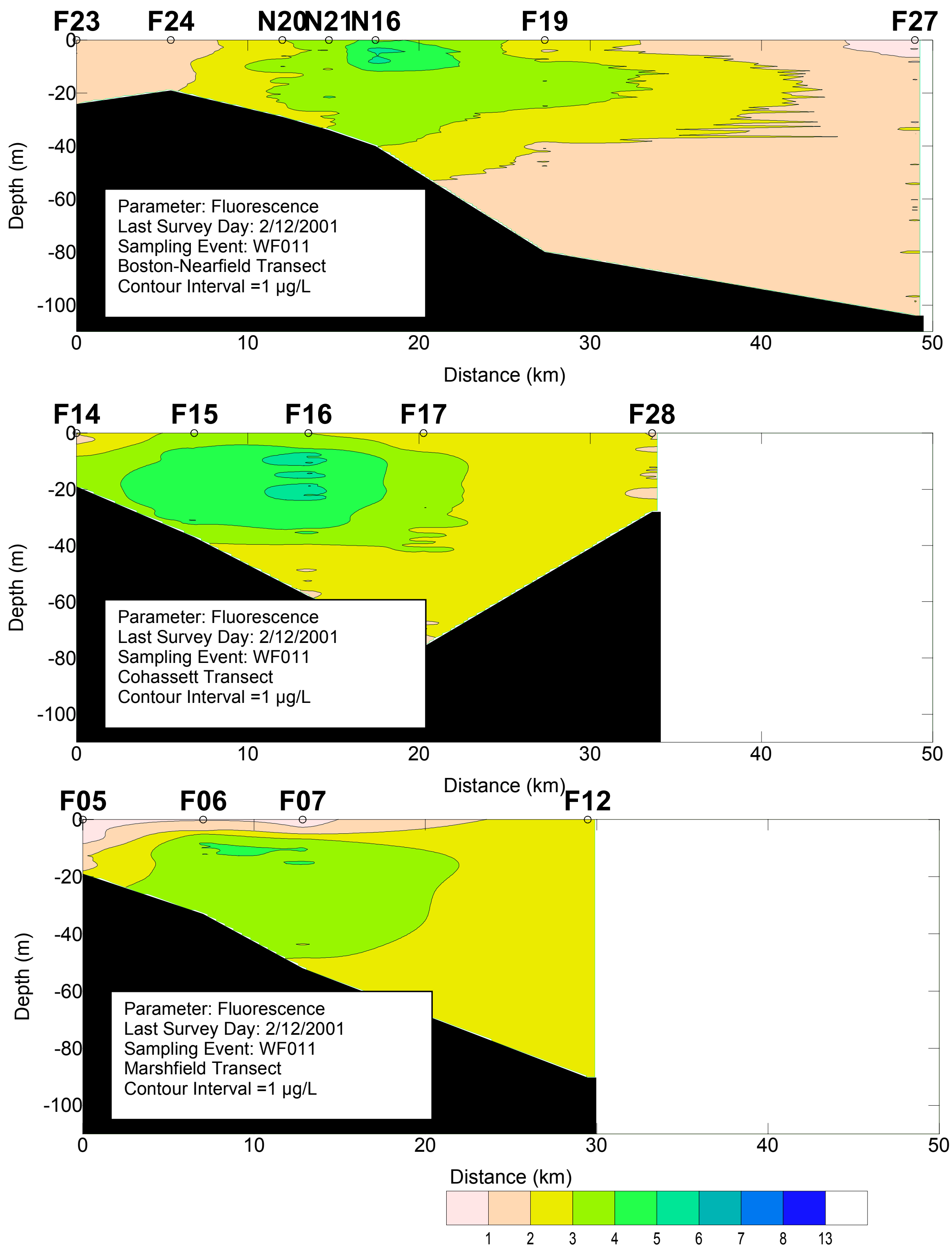


Figure 4-41. Fluorescence Vertical Contour Plots along Three Transects for Farfield Survey WF011 (Feb 01)

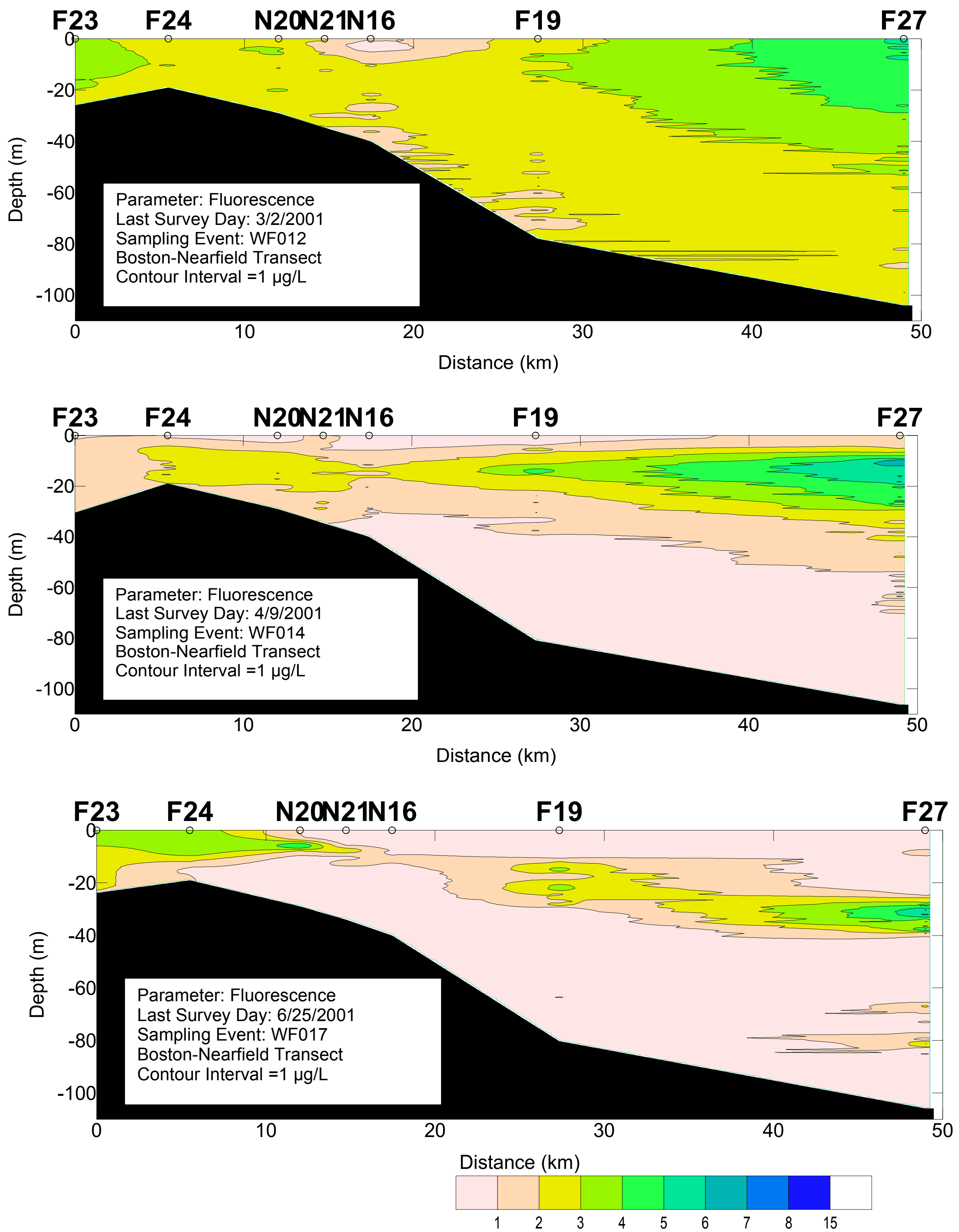


Figure 4-42. Fluorescence Vertical Contour Plots along the Boston-Nearfield Transect for Farfield Surveys WF012, WF014, and WF017

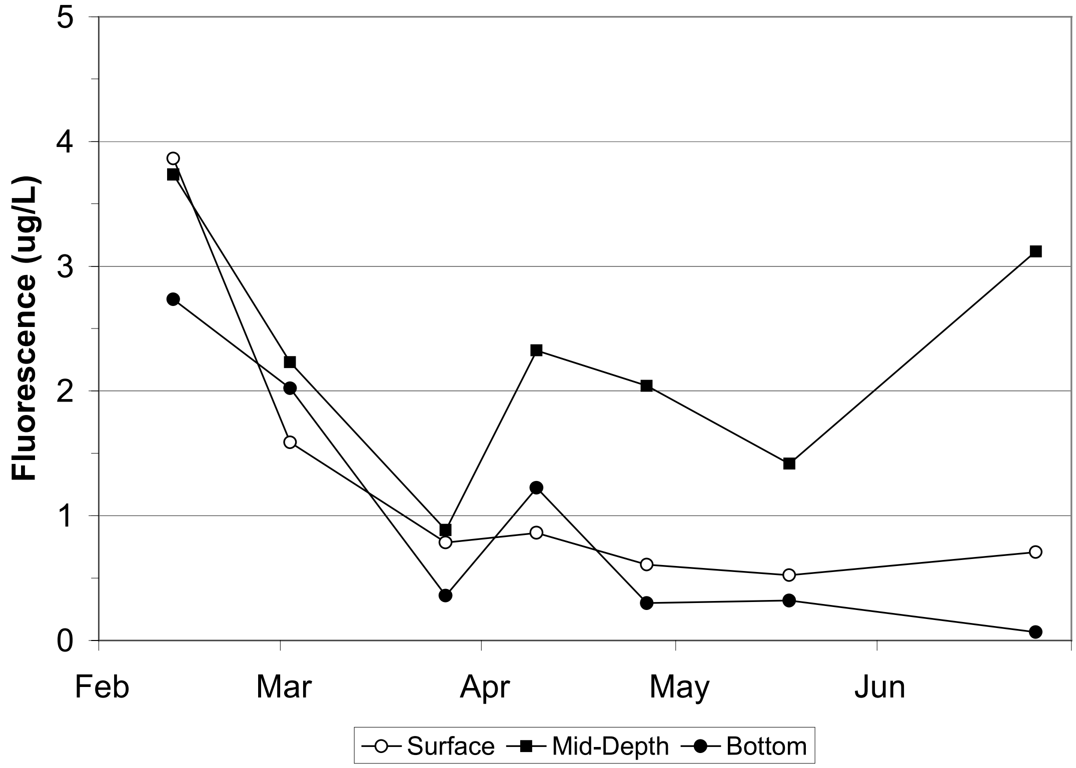
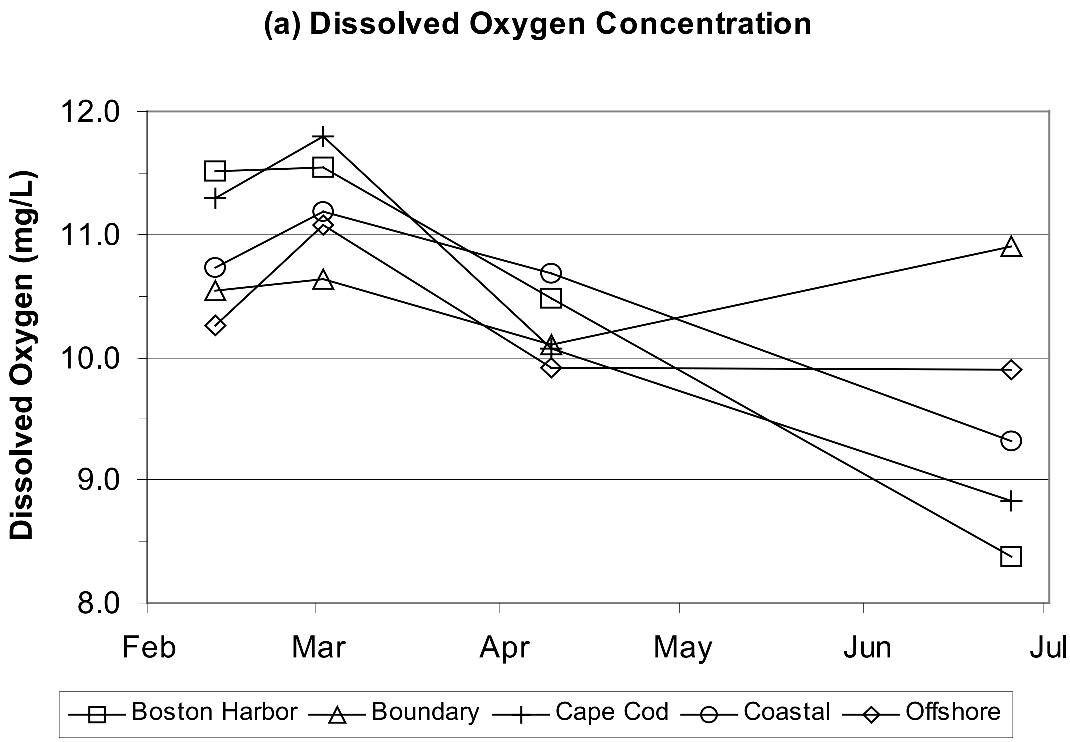


Figure 4-43. Time-Series of Bottom, Mid-Depth, and Surface Survey Mean Chlorophyll Concentration in the Nearfield



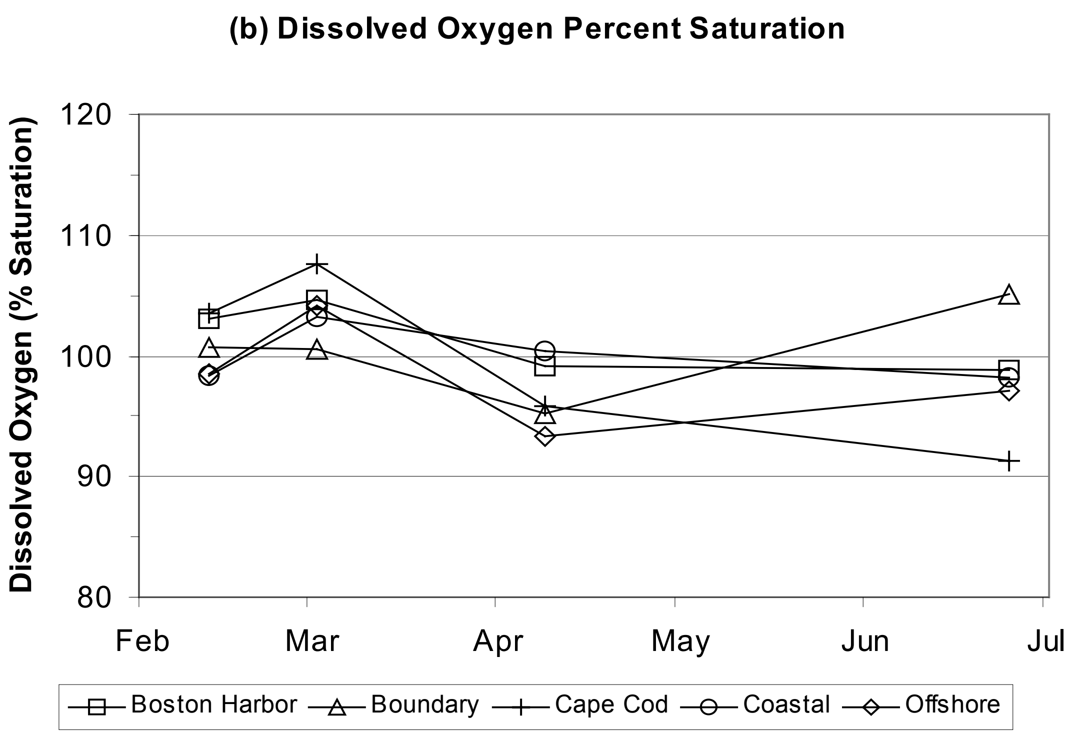


Figure 4-44. Time-Series of Bottom Water Average DO Concentration and Percentage Saturation in the Farfield

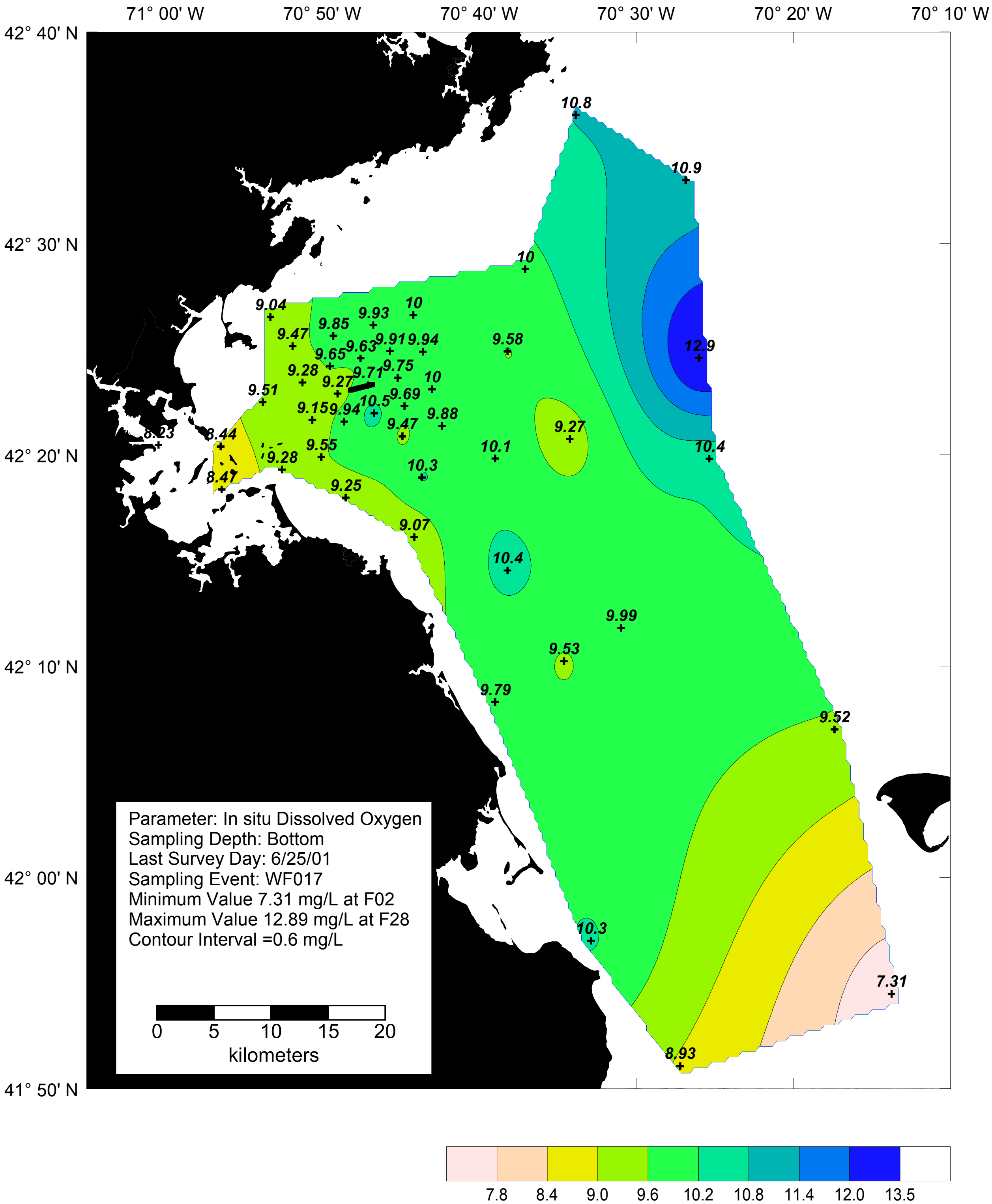
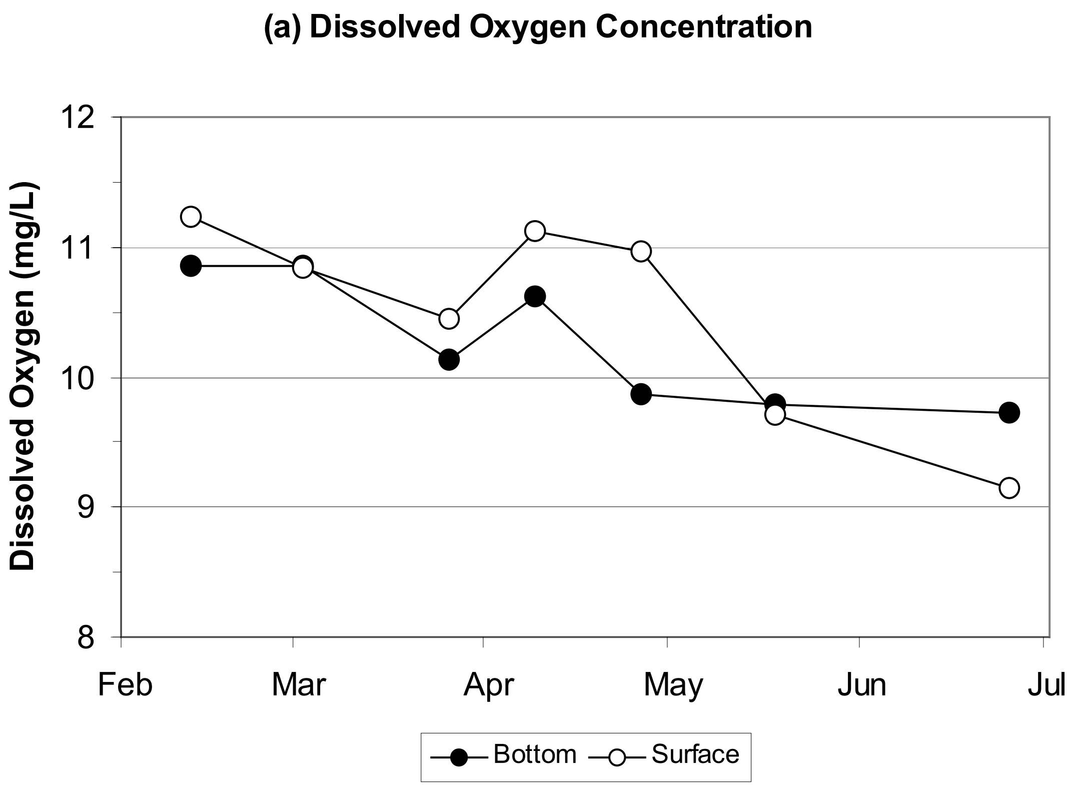


Figure 4-45. Bottom Water Dissolved Oxygen Contour Plot for Farfield Survey WF017 (Jun 01)



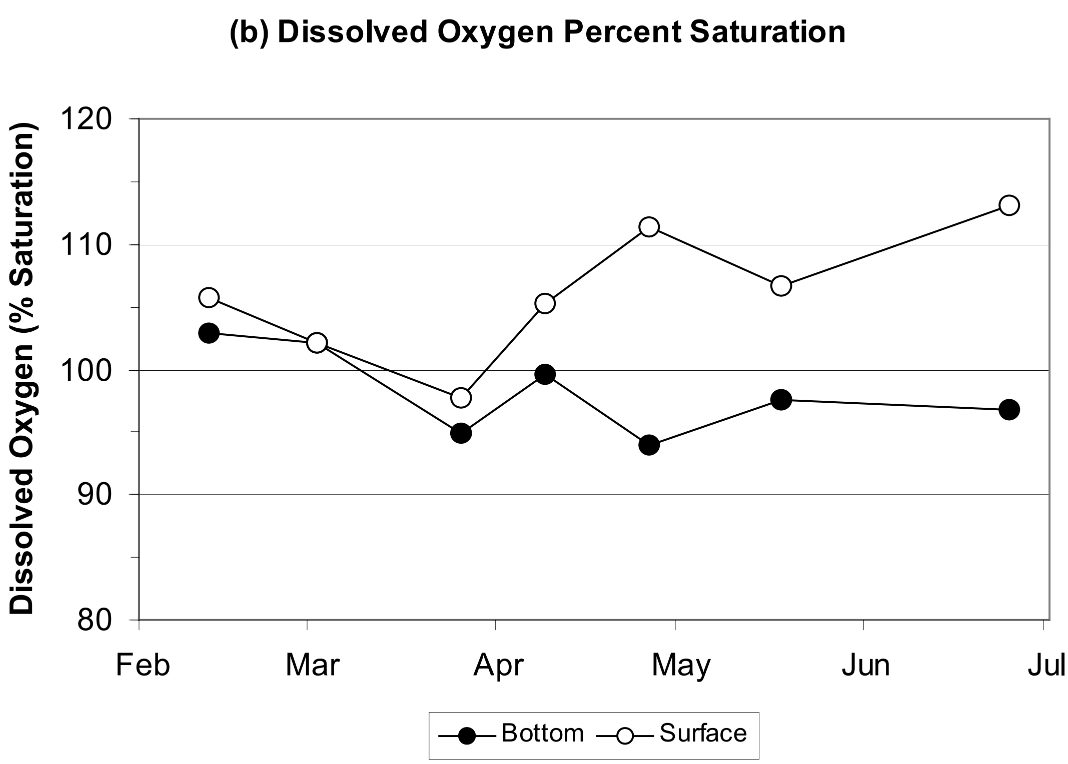


Figure 4-46. Time-Series of Bottom and Surface Average DO Concentration and Percentage Saturation in the Nearfield

5.0 PRODUCTIVITY, RESPIRATION AND PLANKTON RESULTS

5.1 Productivity

Production measurements were taken at two nearfield stations (N04 and N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on February 9 (WF011), March 1 (WF012), April 4 (WF014) and June 25 (WN017). N04 and N18 were additionally sampled on March 26 (WN013), April 26 (WN015), and May 18 (WN016). Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C at varying light intensities as summarized below and in Appendix A.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from a 2π irradiance sensor located on Deer Island, MA. After collection, productivity samples were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (Figure 5-1 and comprehensively in Appendix E) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth.

For this semi-annual report, areal production (mg C m^{-2} d^{-1}) and chlorophyll-specific areal production (mg C mg Chl^{-1} d^{-1}) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity (and chlorophyll-specific productivity) over the depth interval. Chlorophyll-specific productivity for each depth was first determined by normalizing productivity by measured chlorophyll *a*. Productivity, chlorophyll-specific productivity and chlorophyll *a* for each depth are also presented as contour plots (Figures 5-4 to 5-9).

5.1.1 Areal Production

Areal production at the nearfield stations (N04 and N18) was similar throughout much of the semi-annual sampling period (Figure 5-2). Areal production at the two sites was relatively high (~ 875 – 1500 mg C m^{-2} d^{-1}) during the initial cruises in February and March (WF011 and WF012). Values decreased at both sites to ~300 – 650 mg C m^{-2} d^{-1} by late March (WN013). Productivity increased to peak winter-spring bloom levels (1722 – 1876 mg C m^{-2} d^{-1}) at both stations during the April survey (WF014) then decreased again to ~500 mg C m^{-2} d^{-1} by mid-May (WN016). Productivity increased again at both sites during the survey in late June (WF017).

The timing and magnitude of the maximum winter-spring productivity was similar at both stations. The maximum productivity at station N04 occurred in April with a peak production of 1876 mg C m^{-2} d^{-1}. Station N18 reached its maximum seasonal value (1722 mg C m^{-2} d^{-1}) on the same date. These spring peaks at both sites were considerably lower than winter-spring bloom maxima in 2000 when values of 2882 – 4017 mg C m^{-2} d^{-1} were observed. The initial productivity peaks in 2001 occurred simultaneously at both stations in early March but reached a higher level (1494 mg C m^{-2} d^{-1}) at station N04 compared with N18 (1063 mg C m^{-2} d^{-1}). In contrast, during June (WF017) the increase in productivity at station N18 (1336 mg C m^{-2} d^{-1}) was greater than the increase at station N04 (802 mg C m^{-2} d^{-1}). The minimum production at station N18 (307 mg C m^{-2} d^{-1}) was observed in late March. At station N04 the minimum seasonal level was higher (490 mg C m^{-2} d^{-1})

and observed later (May 18, 2001). The patterns observed at the nearfield sites were consistent with those observed during 1999-2000 although the timing of events varied. The patterns were also consistent with patterns seen in chlorophyll distributions (Section 4.2.2).

Boston Harbor displayed a different productivity pattern in comparison with the nearfield sites. At the Boston Harbor productivity/respiration station (station F23), areal production was relatively low (~200 mg C m^{-2} d^{-1}) during the initial February survey. Areal production increased markedly to ~1000 mg C m^{-2} d^{-1} by early March (WF012) then declined to moderate levels (~700 mg C m^{-2} d^{-1}) in April (WF014). Areal production reached a maximal value of 1409 mg C m^{-2} d^{-1} at station F23 during the June survey (WF017). The production data are in agreement with the chlorophyll data throughout the semi-annual period. Elevated chlorophyll values during WF012 (2.2 µg l^{-1}) and WF017 (3.08 µg l^{-1}) were associated with increased productivity levels. During WF011 and WF014, average chlorophyll values at station F23 were relatively low, ranging from 1.18 to 1.25 µg l^{-1}, and associated with lower phytoplankton production.

Areal production in 2001 followed patterns typically observed in prior years. Distinct winter-spring phytoplankton blooms were observed at both nearfield stations during the sampling period (Figure 5-2). In general, nearfield stations are characterized by the occurrence of a winter-spring bloom. The winter-spring blooms observed at nearfield stations in 1995-2000 generally reached values of 1000 to 4000 mg C m^{-2} d^{-1}, with blooms typically lasting 2-3 months. The bloom in 2001 reached peak values of > 1700 mg C m^{-2} d^{-1} and lasted from March through April.

In general, the Boston Harbor site (station F23) exhibits a gradual pattern of increasing areal production from winter through summer rather than the distinct winter-spring peaks observed at the nearfield sites. In 2001 the pattern for station F23 did not conform to this description. Production values increased from February through March but decreased in April before reaching the seasonal maximum in June (Figure 5-2). During 1995-2000, peak areal productions at station F23 ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal production observed in 2001 was somewhat lower but also occurred in June.

5.1.2 Chlorophyll-specific Production

Depth-averaged chlorophyll-specific production was similar at both nearfield sites over time (Figure 5-3). Depth-averaged chlorophyll-specific production was relatively low (<10 mg C mg Chl a^{-1} d^{-1}) in February. Chlorophyll-specific production increased at both stations by early March (WF012) to values of 16-21 mg C mg Chl a^{-1} d^{-1}. Values decreased again during late March then increased to levels >50 mg C mg Chl a^{-1} d^{-1} at both sites in early April. The seasonal nearfield maximum was reached at station N18 in early April (65.8 mg C mg Chl a^{-1} d^{-1}). At station N04 the seasonal maximum (54.3 mg C mg Chl a^{-1} d^{-1}) was observed on 26 April (WN015). Depth-averaged chlorophyll-specific production gradually declined during the mid-May and late-June sample periods at the nearfield sites. Seasonal maxima at the nearfield sites were greater than 50 mg C mg Chl a^{-1} d^{-1}. By comparison chlorophyll-specific rates at harbor station F23 did not exceed 25 mg C mg Chl a^{-1} d^{-1} throughout the sampling cycle (Figure 5-3). The peak chlorophyll-specific rate at station F23 did coincide in time with the peak observed at stations N18 on 4 April, although at a lower rate.

Chlorophyll-specific production is an approximate measure for the efficiency of production and frequently reflects nutrient conditions at the sampling sites. The distribution of chlorophyll-specific production indicates that the efficiency of production was high relative to the amount of biomass present at the nearfield stations. At both stations N04 and N18 the peak chlorophyll-specific production occurred during or close to the winter-spring production peak. By contrast, efficiency of production was low at the Harbor site relative to biomass availability.

5.1.3 Production at Specified Depths

The spatial and temporal distribution of production, chlorophyll and chlorophyll-specific production on a volumetric basis were summarized by showing contoured values over the sampling period (Figures 5-4 to 5-9). Chlorophyll-specific productions (daily production normalized to chlorophyll concentration at each depth) were calculated to compare production with chlorophyll concentrations. Chlorophyll-specific production can be used as an indicator of the optimal conditions necessary for photosynthesis.

The areal productivity peaks reported during early February - April 2001 at stations N04 and N18 were concentrated in the upper 15 m of the water column (Figures 5-4 and 5-5). At station N04, production was highest (113 mg C m^{-3} d^{-1}) in the surface water on February 9 while a mid-surface to mid-depth (6 – 13.5 m) productivity maximum (78 – 85 mg C m^{-3} d^{-1}) was observed on April 4. At station N04 productivity tended to decrease following the spring peak values. At station N18, productivity also decreased following the spring phytoplankton bloom but increased again in June. Peak production (110 mg C m^{-3} d^{-1}) at station N18 occurred in the surface water on February 9 and was similar to the level observed at N04. Depth-specific production at station N18 was further characterized by a subsurface productivity maximum located at mid-surface and mid-water depths during the winter-spring bloom peak. Elevated production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements during the initial winter-spring bloom period (Figures 5-7 and 5-8). However, the seasonal maxima in production at both nearfield sites occurred during a period of lower chlorophyll *a* concentrations suggesting an increase in the efficiency of production at this time.

The productivity pattern at specified depths observed in 2001 was similar to that observed in prior years. At station N04 productivity as high as 45 mg C m^{-3} d^{-1} occurred to depths of 20 m. At station N18 productivity >30 mg C m^{-3} d^{-1} was rarely observed at depths >20 m. Unlike prior years, elevated productivity (>20 mg C m^{-3} d^{-1}) in the Harbor was detected at depths >20 m. Productivity in the harbor has generally been restricted to the upper 10 m of the water column.

Chlorophyll-specific productions at N04 and N18 tended to be concentrated in the upper portions of the water column (Figures 5-8 and 5-9). Chlorophyll-specific productions increased throughout the sampling season reaching peak depth-specific values at station N04 in late April and during May - June 2001 at station N18. At station N04, the peak depth-specific production per unit chlorophyll *a* coincided with the peak chlorophyll-specific areal production. At station N18 the peak chlorophyll-specific areal productivity occurred in early April (Figure 5-3), when elevated production per unit chlorophyll a was distributed throughout the upper 18 m of the water column. The seasonal maxima observed during May-June at station N18 were confined to the upper 6 m. The increased chlorophyll-specific production observed during April 2001 at station N04 and May-June 2001 at station N18 did not lead to elevated phytoplankton biomass (Figures 5-6 and 5-7). When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as total chlorophyll *a*) it suggest that other processes (such as predation by zooplankton) are important in controlling the patterns observed.

5.2 Respiration

Respiration measurements were made at the same nearfield (N04 and N18) and farfield (F23) stations as productivity and at an additional station in Stellwagen Basin (F19). All four stations were sampled during each of the combined farfield/nearfield surveys. Stations N04 and N18 were also sampled during the three nearfield only surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 8±1 days.

Both respiration (in units of $\mu MO_2\ hr^{-1}$) and carbon-specific respiration ($\mu MO_2\ \mu MC^{-1}\ hr^{-1}$) rates are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

5.2.1 Water Column Respiration

During the surveys conducted in February and March (WF011, WF012 and WN013), respiration rates were low in both the nearfield and farfield areas (<0.10 μMO_2hr^{-1}; Figures 5-10 and 5-11). In April (WF014), respiration rates remained low in both the nearfield and farfield with all values <0.10 μMO_2hr^{-1} except for the surface water at station F19 that was slightly higher (0.14 μMO_2hr^{-1}). Rates in the surface waters at nearfield stations N04 and N18 were >0.10 μMO_2hr^{-1} in late April, but decreased to <0.10 μMO_2hr^{-1} in May. Bottom and mid-depth water respiration rates remained <0.10 μMO_2hr^{-1} through May. The low respiration rates during the winter/spring of 2001 are likely due to the lack of a major bloom in Massachusetts Bay and thus less organic material to respire. POC concentrations remained at or below 20 µM in the nearfield from February to May (Figure 5-12a). The winter/spring 2001 respiration rates and POC concentrations in the nearfield were about half the values measured in 2000, which had a major winter-spring *Phaeocystis* bloom.

By June (WF017), respiration rates had increased at each of the stations, but most substantially at station N18. Surface water respiration increase to 0.13 μMO_2hr^{-1} at station N18, which was comparable the rates in the surface and mid-depth waters at station N04. At station N18, mid-depth respiration increased to almost 0.3 μMO_2hr^{-1} and to 0.4 μMO_2hr^{-1} in the bottom waters. Respiration rates remained relatively low in Boston Harbor ranging from 0.12 in the bottom waters to 0.17 at mid-depth. At station F19, bottom and mid-depth rates remained <0.1 μMO_2hr^{-1} in June, but surface water respiration increased to 0.22 μMO_2hr^{-1}. It is unclear why respiration rates were so much higher at station N18 compared to station N04 and the farfield stations. In comparison to stations N04 and F19, station N18 is shallower and had warmer bottom water temperatures and was more strongly stratified than these deeper stations, which may have contributed to higher respiration rates. Station N18 is also ~2km downstream of the diffuser and more likely to be impacted by particles in the effluent, and the BOD drain it might put on the system. The potential influence of effluent on nearfield POC concentrations and respiration rates will be investigated further in the 2001 annual report.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration accounts for the effect variations in the size of the particulate organic carbon (POC) pool have on respiration. Differences in carbon-specific respiration result from variations in the quality of the available particulate organic material or from environmental conditions such as temperature. Particulate organic material that is more easily degraded (more labile) will result in higher carbon-specific respiration. In general, newly produced organic material is the most labile. Water temperature is the main physical characteristic that controls the rate of microbial oxidation of organic material – the lower the temperature the lower the rate of oxidation. When stratified conditions exist, the productive, warmer surface and/or mid-depth waters usually exhibit higher carbon-specific respiration rates and bottom waters have lower carbon-specific respiration rates due to both lower water temperature and lower substrate quality due to the degradation of particulate organic material during sinking.

POC concentrations were relatively low (~20 μM) in the nearfield from February to mid-May (Figure 5-12). During this time period nearfield POC concentrations peaked in the surface waters at 26 and 27 μM, in early February and late April, respectively. In Boston Harbor (station F23), POC concentrations were similarly low in February and by April had only increased to 26 μM in surface and bottom waters and 29 μM at mid-depth (Figure 5-13). At offshore station F19, low concentrations were observed during the two February surveys, but there was a larger increase in POC in April. Bottom water concentration remained relatively low (24 μM), but POC concentration at mid-depth had increased to 36.5 μM and in the surface waters POC concentration had reached 65 μM. The carbon-specific respiration rates were low (≤0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$) in the nearfield from early February to early April increasing to >0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$ in surface and bottom waters at station N18 in late April and in at mid-depth at station N04 in May (Figure 5-14). At the farfield stations during the February and April surveys, carbon specific respiration rates were at a maximum during the early February survey (>0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$ in surface waters at station F23 and in mid-depth and bottom waters at station F19; Figure 5-15). Carbon specific respiration rates remained <0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$ from late February to June at Boston Harbor station F23. At station F19, the high POC concentrations in April did not translate into elevated respiration rates and carbon specific respiration for both the February and April surveys was ≤0.003 $\mu MO_2\mu MC^{-1}hr^{-1}$. The elevated POC concentrations at station F19 during the April survey was likely due to the *Phaeocystis* bloom for which the highest abundances were observed at the boundary and northern offshore stations (F22, F26, and F27). Surface water temperatures remained low in this area (<5°C) and likely inhibited respiration.

POC concentrations increased at station N18 from ~20 μM at each depth in May to 34 μM in surface, 48μM in mid-depth, and 62 μM in bottom waters. This increase occurred even though there was a decrease in phytoplankton abundance in surface and mid-depth waters at station N18 from mid-May to June (see Figures 5-16 and 5-17). Given the proximity to the diffuser, it is likely that effluent contributed input to the increase in POC at station N18. The increase in POC at station N18 did coincide with the large increase in respiration and an increase in carbon specific respiration to 0.006 and 0.007 $\mu MO_2\mu MC^{-1}hr^{-1}$ in mid-depth and bottom waters, respectively. The availability of organic carbon and the increasing temperatures in mid-depth and bottom waters contributed to the increase in respiration at station N18 in June. A smaller increase in POC concentrations was observed at station N04 from <20 μM in May to 21 to 44μM in June, which also coincided with a decrease in phytoplankton abundance. In Boston Harbor, POC concentrations increased slightly over the entire water column from April to June, while there was a sharp decrease in POC concentration at all depths at station F19 (Figure 5-13). Carbon specific respiration rates remained low (<0.005 $\mu MO_2\mu MC^{-1}hr^{-1}$) in Boston Harbor in June, but there was a large increase in carbon specific respiration in the surface water at station F19 from 0.003 $\mu MO_2\mu MC^{-1}hr^{-1}$ in April to 0.012 $\mu MO_2\mu MC^{-1}hr^{-1}$ in June. Overall, carbon-specific respiration in the harbor and nearfield was relatively low during this time period. The only time carbon specific respiration exceeded 0.01 $\mu MO_2\mu MC^{-1}hr^{-1}$ was in the surface waters at station F19 in June. These low numbers suggest that there were limited supplies of labile POC available during the winter/spring of 2001, which is congruent with the lack of a major winter/spring bloom in Massachusetts Bay in 2001.

5.3 Plankton Results

Plankton samples were collected on each of the seven surveys conducted during this reporting period. Phytoplankton and zooplankton samples were collected at two stations during each nearfield survey (N04 and N18) and at 13 farfield and the two nearfield stations (total = 15) during the farfield surveys. Two additional stations were sampled for zooplankton in Cape Cod Bay (F32 and F33) during the first three farfield surveys (WF011, WF012, and WF014). Phytoplankton samples included both whole-water and 20 µm-mesh screened samples, from the surface and subsurface chlorophyll maximum depths. Zooplankton samples were collected by vertical/oblique tows with 102 µm-mesh nets. Methods of sample collection and analyses are detailed in Albro *et al*. (1998).

In this section, the seasonal trends in plankton abundance and regional characteristics of the plankton assemblages are evaluated. Total abundance and relative abundances of major taxonomic groups are presented for each phytoplankton and zooplankton community. Tables in the appendices provide data on cell and animal densities and relative abundance for all dominant plankton species (>5% abundance): Appendix F – whole water phytoplankton, Appendix G – 20-µm screened phytoplankton, and Appendix H – zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundances in nearfield whole water samples (surface and mid-depth) were variable from February through June (Table 5-1; Figures 5-16 and 5-17). Total abundances were low and varied between approximately 0.26 –0.57 x 10^6 cells L^{-1} in February- March. Abundances increased somewhat in April (WF014 and WN015) to levels of 0.65-1.56 x 10^6 cells L^{-1}. Abundances increased in May to levels of 0.84-2.27 x 10^6 cells L^{-1}, declining slightly to levels of 0.34-1.33 x 10^6 cells L^{-1} in June.

Total phytoplankton abundance in farfield whole water samples (surface and mid-depth) showed similar low abundances in February and early March with levels of 0.18-1.61 x 10^6 cells L^{-1} during surveys WF011 and WF012 (Table 5-1; Figures 5-18 and 5-19). The highest abundances were observed at Cape Cod Bay stations F01 and F02. By early April (WF014) farfield abundances jumped to 0.31-3.38 x 10^6 cells L^{-1} (Figure 5-20). By June (WF017) phytoplankton abundances had declined, to levels of < 2.0 x 10^6 cells L^{-1}, except at stations in Boston Harbor (stations F23, F30, and F31) and in the coastal domain (stations F13, F24, and F25), where levels at some stations approached 4.42 x 10^6 cells L^{-1} (Figure 5-21).

Total abundances of dinoflagellates, silicoflagellates and protozoans in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Dinoflagellates and silicoflagellates in nearfield and farfield screened phytoplankton samples were < 2.37 x 10^3 cells L^{-1} from February through early March, remaining at levels < 2.83 x 10^3 cells L^{-1} during late April, rebounding to values as high as > 18.8 x 10^3 cells L^{-1} by late June (Table 5-2).

Table 5-1. Nearfield and farfield averages and ranges of abundance (10^6 cells/l) of whole-water phytoplankton

Survey	Dates (2001)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF011	2/7-9, 2/12	0.52	0.37-0.57	0.59	0.24-1.61
WF012	2/27-28, 3/1-2	0.35	0.26-0.44	0.41	0.18-1.02
WN013	3/26	0.44	0.37-0.49	–	–
WF014	4/4-6, 4/9	1.21	1.08-1.56	1.07	0.31-3.38
WN015	4/26	0.79	0.65-0.99	–	–
WN016	5/18	1.33	0.84-2.27	–	–
WF017	6/19-21, 6/25	0.7	0.34-1.33	1.67	0.07-4.42

Table 5-2. Nearfield and farfield average and ranges of abundance (cells/l) for >20 µm-screened dinoflagellates

Survey	Dates (2001)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF011	2/7-9, 2/12	1448	998-1968	759	166-2373
WF012	2/27-28, 3/1-2	642	498-983	520	158-1205
WN013	3/26	194	125-255	–	–
WF014	4/4-6, 4/9	634	403-863	453	143-1225
WN015	4/26	1598	365-2830	–	–
WN016	5/18	3299	1314-5899	–	–
WF017	6/19-21, 6/25	8471	4043-17035	5190	1125-18865

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – In February to early March (WF011and WF012), nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates < 10 µm in diameter, cryptomonads, centric diatoms such as *Thalassiosira* spp. 10 - 20 µm in diameter and other centric diatoms such as *Thalassiosira nordenskioldii* and *Guinardia delicatula* (Figures 5-16 and 5-17). In late March (WN013) microflagellates, to a lesser extent cryptomonads, and centric diatoms such as *Thalassiosira nordenskioldii* and *Chaetoceros debilis* were dominant in the nearfield. In early April (WF014), *Phaeocystis pouchetii* became dominant, comprising 52 - 77% of total cells in the nearfield (marked as "Other" in Figures 5-16 and 5-17). Microflagellates accounted for the remainder of cells recorded. By late April (WN015) *Phaeocystis* had disappeared, and from May through June there was increasing abundance and dominance of microflagellates < 10 µm in diameter, cryptomonads, and centric diatoms such as *Skeletonema costatum*, and *Thalassiosira* sp. In June (WF017), microflagellates dominated in the nearfield (68-81%), with lesser contributions by cryptomonads, and at subsurface depths, the dinoflagellate *Ceratium longipes* (5-10%) and various centric diatoms, including *Chaetoceros compressus*.

Screened Phytoplankton - In early February (WF011), nearfield screened samples were dominated by the thecate dinoflagellates *Prorocentrum micans* and *Ceratium tripos*, and the silicoflagellate *Distephanus speculum.* In late February – early March (WF012) dominants were the dinoflagellates *Ceratium fusus, C. longipes, C. tripos, Prorocentrum micans* and a large (up to 80 µm in longest dimension) species of the dinoflagellate genus *Protoperidinium*, as well as the silicoflagellate

Distephanus speculum. In late March (WN013), these same taxa were abundant in varying proportions, as well as an unidentified athecate dinoflagellate, and the thecate dinoflagellates *Dinophysis norvegica*, and a small (< 40 µm in longest dimension) species of the dinoflagellate genus *Protoperidinium.* The same taxa were abundant in early April (WF014). By late April (WN015), *Ceratium longipes, C. tripos,* other species of the genus *Ceratium*, *Prorocentrum minimum*, *Protoperidinium* spp. and other thecate and athecate dinoflagellates were dominant.

By early May (WN016), *Ceratium longipes*, *C. tripos*, and *Prorocentrum minimum* were dominant. In June (WF017) there was continued dominance by *C. fusus, C. longipes* and *C. tripos*, and various other species of the genus *Ceratium*.

5.3.1.3 Regional Phytoplankton Assemblages

Whole-Water Phytoplankton - Whole-water phytoplankton assemblages at farfield stations were generally similar to those in the nearfield during the same time periods, in terms of composition, abundance, and the major *Phaeocystis* bloom in April.

During early February (WF011), most farfield station assemblages were dominated at both depths by the same assemblages that dominated nearfield stations. These included unidentified microflagellates, cryptomonads, and diatoms of the genus *Thalassiosira, Chaetoceros,* and at some stations *Skeletonema costatum* and *Thalassionema nitzschoides* (Figure 5-18), and at station F23, the diatom *Eucampia cornuta*. During late February and early March (WF012) most farfield stations were dominated by microflagellates and the same diatoms as during WF011 (Figure 5-19). A winter/spring bloom of centric diatoms was observed in Cape Cod Bay, but not in Massachusetts Bay.

In April (WF014), most farfield stations were overwhelmingly dominated by *Phaeocystis pouchetii* (Figure 5-20), accounting for up to 85% and 93% of cells recorded for surface and subsurface depths, respectively (means = 43% for the surface and 52% for the subsurface depths). The remainder of cells counted included comparatively minor contributions by unidentified microflagellates (5-86%), with much lesser contributions by cryptomonads, centric diatoms, and at station F01 at the surface, a small < 20 µm dinoflagellate of the genus *Gymnodinium*. The *Phaeocystis* bloom occurred in Cape Cod Bay, but in small proportions compared to the overwhelming dominance in Massachusetts Bay (Figure 5-20).

By June (WF017), assemblages at both depths at most farfield stations were dominated by the same microflagellates and cryptomonads that dominated the nearfield (Figure 5-21). Subdominant diatom taxa were the same as those recorded for the nearfield during this period (*Skeletonema costatum, Chaetoceros* spp., and the dinoflagellates *Ceratium longipes* and a small *Gymnodinium* sp.).

Screened Phytoplankton - Screened-water dinoflagellate assemblages at farfield stations were similar to those in the nearfield during the same time periods.

In early February (WF001), 20 µm-screened surface phytoplankton samples from the farfield were dominated by *Ceratium tripos*, *Prorocentrum micans* and *Distephanus speculum*, as in the nearfield, although the silicoflagellate *Dictyocha fibula* was also moderately abundant at some sub-surface stations. During late February – early March (WF012) farfield assemblages were dominated by these same taxa, as well as those recorded for the nearfield.

In April (WF014), farfield assemblages were dominated by *Ceratium tripos, C. fusus*, and *C. longipes*, and *Dictyocha fibula* with lesser contributions by *Dinophysis norvegica* and

Protoperidinium spp. and the silicoflagellate *Distephanus speculum* at some stations. Screened farfield samples in June (WF017) were dominated by the same assemblages as in the nearfield, including species of the dinoflagellate genus *Ceratium* (*fusus, longipes, tripos*).

5.3.1.4 Nuisance Algae

The major bloom of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July 2001 was the April bloom of *Phaeocystis pouchetii*. At cell concentrations of 0 - 3.13 x 10^6 cells L^{-1} (mean = 0.67 x 10^6 cells L^{-1}), the 2001 *Phaeocystis pouchetii* bloom did not begin to approach the levels of the 2000 bloom (0.233-12.258 x 10^6 cells L^{-1}; mean = 6.2 x 10^6 cells L^{-1}). Also, the occurrence of back-to-back *Phaeocystis* blooms in 2000 and 2001 is a break from the pattern that had been observed during baseline monitoring of these blooms occurring in cycles of about 3 years – 1992, 1994, 1997, and 2000 (Libby *et al*, 2001). This departure from the pattern observed during baseline monitoring will be evaluated in more detail in the 2001 Annual Water Column Report.

The toxic dinoflagellate *Alexandrium tamarense* was only sporadically recorded in trace levels. Single cells were recorded for whole-water samples from station N04 during WF014, and station N18 during WF017. There was a single recording of *A. tamarense* from screened-water samples, at 2.5 cells L^{-1} from station N04 during WN015. There were a few additional occurrences of "*Alexandrium* spp." in screened samples that were not positively identified as *A. tamarense*. These included abundances of 15 cells L^{-1}, once in April (WF015), once in May (WN016) at an abundance of 4.3 cells L^{-1} at station N18, and at abundances of 2.5 – 35 cells L^{-1}, at 5 stations (N04, N16, N18, F13, F25, F26) during the June survey (WF017). Thus, abundance of *Alexandrium tamarense* plus *Alexandrium* spp. in screened samples in 2001 was typically low, as in most previous years. Levels since 1994 have not approached those of 1993.

Pseudo-nitzschia pungens was also found sporadically in low abundance, and it never comprised > 5% of cells counted in a given sample. During WF011, *P. pungens* was recorded for 25 samples from 14 stations, but never at abundances > 20,600 cells L^{-1}. During WF012, *P. pungens* was recorded for 18 samples from 12 stations. Half of these were for a single cell only. Abundances never exceeded 24,300 cells L^{-1}. During WN013, *P. pungens* was recorded for all 4 samples from both nearfield stations, but at < 3,800 cells L^{-1}. During WF014, *P. pungens* was recorded for 27 samples from 14 stations at abundances < 14,700 cells L^{-1}. Thereafter, during WN015, WN016, and WF017, *P. pungens* was recorded for 2 samples in each survey, at abundances < 8,400 cells L^{-1}. In summary, nominal *P. pungens* (which could include some toxic *P. multiseries*) was frequently present in the first half of 2001, but never abundant.

Although *Phaeocystis, Alexandrium tamarense and Pseudo-nitzshia* were all observed in February to June 2001, none of their abundances exceeded the caution threshold values.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations generally remained low (< 10.7 – 29.7 x 10^3 animals m^{-3}) from February through April (Table 5-3; Figure 5-22). Values increased somewhat in May, but declined again in June at station N18 (Figure 5-22a). The May increase was more dramatic at station N04, before a similar June decline (Figure 5-22c). The low zooplankton abundance values in the first half of 2001 were in stark contrast to values for the same period in the previous year. The maximum 2000 nearfield values of 146-290 x 10^3 animals m^{-3} recorded in June and July (WF007, WN008 and WN009) were among the highest during the entire 1992-2000 baseline period.

Total zooplankton abundance at farfield stations in February was generally low (with 3 exceptions, < 20 x 10^3 animals m^{-3} for WF011 and with 2 exceptions > 20 x 10^3 animals m^{-3} for WF012; Figure 5-23). By April (WF014), total zooplankton abundance at farfield stations had increased slightly, with values at 3 of the stations of > 30 x 10^3 animals m^{-3}, but most were < 20 x 10^3 animals m^{-3} (Figure 5-24a). Zooplankton abundance in Boston Harbor had increased by June (WF017) to include 2 stations with levels >60 x 10^3 animals m^{-3} but most values elsewhere in the farfield remained < 30 x 10^3 animals m^{-3} (Figure 5-24b).

Table 5-3. Nearfield and farfield average and ranges of abundance (10^3 animals/m^3) for zooplankton

Survey	Dates (2001)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF011	2/7-9, 2/12	21.1	14.9-28.4	12.0	2.9-23.1
WF012	2/27-28, 3/1-2	12.1	10.7-13.4	12.0	2.0-23.5
WN013	3/26	19.4	16.2-22.7	–	–
WF014	4/4-6, 4/9	14.4	12.2-16.0	20.7	4.2-41.5
WN015	4/26	25.5	21.4-29.7	–	–
WN016	5/18	43.3	32.0-54.7	–	–
WF017	6/19-21, 6/25	10.8	9.7-11.9	30.9	9.0-82.6

5.3.2.2 Nearfield Zooplankton Community Structure

Nearfield zooplankton assemblages (Figure 5-22) during early February (WF011) were dominated by copepod nauplii (45-46%), as well as copepodites of *Oithona similis* (40-45%). In late February – early March (WF012), the same patterns occurred with dominance by copepod nauplii (37-39%) and *Oithona similis* (37-38%) and barnacle nauplii (up to 11%) and *Pseudocalanus* spp. (6%) copepodites. A similar assortment was also found in late March (WN013) with nearfield dominance by copepod nauplii (52-55%), *Oithona similis* copepodites (15-18%) and *Pseudocalanus* spp. (6%) copepodites.

At nearfield stations during early April (WF014), zooplankton assemblages were dominated by copepod nauplii (39-47%) and copepodites of *Oithona similis* (18%) and copepodites of *Calanus finmarchicus* (10-14%), *Oikopleura dioica* (8-10%) and gastropod veligers (up to 19%). In late April, during WN015 and early May (WN016), nearfield zooplankton assemblages continued to be dominated by the combination of copepod nauplii (18-39%), copepodites of *Oithona similis* (19-27%), and *Pseudocalanus* spp. copepodites (9-11%), with minor contributions (< 10-15%) by bivalve and gastropod veligers, and *Temora longicornis* and *Calanus finmarchicus* copepodites. At nearfield stations during June (WF017), zooplankton assemblages were dominated by copepod nauplii (12-14%)copepodites of *Oithona similis* (15-17%), and *Pseudocalanus* spp. (11-20%).

5.3.2.3 Regional Zooplankton Assemblages

Zooplankton assemblages at farfield stations during early February (WF011) were generally similar to those in the nearfield (Figure 5-23a). Abundant taxa throughout the area included copepod nauplii (17-56%) and *Oithona similis* copepodites and females (12-60% for all stations except F30 and F31 in Boston Harbor). Minor contributions (< 10%) at certain stations came from copepodites of

Pseudocalanus spp. and *Centropages* spp. At stations F30 and F31 in Boston Harbor barnacle nauplii comprised 33-63% of total counts. In late February (WF012; Figure 5-23b), copepod nauplii were dominant (26-67%), followed by *Oithona similis* copepodites and females (12-51%) throughout the study area, except for stations F31 and F23 in Boston Harbor. Barnacle nauplii sporadically comprised up to 11-42% of animals counted at various stations outside Boston Harbor, but 29-86% of total counts at stations F23, F30 and F31 inside the harbor. There were also sporadic contributions at some stations by polychaete larvae (up to 5-14%) and *Pseudocalanus* spp. copepodites (6-11%).

In early April (WF014; Figure 5-24a), copepod nauplii were dominant at all farfield stations (27-50%), as were *Oithona similis* copepodites (8-26%) at all stations except station F30 in Boston Harbor. *Calanus finmarchicus* comprised up to 8-17% of abundance at most stations. There were sporadic contributions at several stations by *Oikopleura dioica* (up to 5-16%) and *Pseudocalanus* spp. copepodites (up to 5-20%). Sporadic minor (< 10%) contributions came from various meroplankters, including bivalve and gastropod veligers, barnacle nauplii, and echinoderm plutei, but polychaete larvae comprised 9-39% of total abundance at stations F30 and F31 in Boston Harbor.

During June (WF017), farfield zooplankton assemblages (Figure 5-24b) were again dominated by copepod nauplii (14-37% for all stations except F22), copepodites of *Oithona similis* (10-57% for all stations except in Boston Harbor), and *Pseudocalanus* spp. (up to 10-24% at 7 stations where present). There were also sporadic contributions at some stations from bivalve veligers (up to 17-27%), *Calanus finmarchicus* copepodites (17% at station F27), *Centropages* spp. copepodites (up to 5-19%), and *Evadne nordmani* (5% at station F26). *Acartia* spp. adults and copepodites accounted for 52 and 64% of total abundance at stations F23 and F30, respectively, in Boston Harbor, and *Acartia* spp. copepodites comprised 9% of abundance at station F31 in Boston Harbor.

In summary, zooplankton assemblages during the first half of 2001 were comprised of taxa typically recorded for the same time of year in previous years.

5.4 Summary of Biological Results

- Areal production peaked (~1900 mg C m^{-2} d^{-1}) at station N18 in the nearfield in early April, but 2001 winter/spring peak production rates were considerably lower than winter-spring bloom maxima for 2000 when values of 2882 – 4017 mg C m^{-2} d^{-1} were observed.
- Boston Harbor station F23 did not conform to the typical pattern of a gradual increase in areal production from winter through summer as production values increased from February through March but decreased in April before reaching the seasonal maximum in June (1409 mg C m^{-2} d^{-1}).
- During previous years (1995-2000), peak areal productions at station F23 ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal production observed in 2001 was lower but the time of the peak (June) was the same.
- Respiration rates in 2001 were much lower than those measured in 1999 and 2000. The low respiration rates during the winter/spring of 2001 were related to the low concentrations of organic carbon and expected low rate of transfer of carbon to bottom waters because of the lack of a substantial bloom in 2001.
- The main exception to the trend towards low respiration and low POC concentrations was the elevated rates and concentrations at station N18 in June. This may have been due to the influence of effluent from the nearby outfall.

- Whole-water phytoplankton assemblages were dominated by unidentified microflagellates and several species of centric diatoms except during the April *Phaeocystis* bloom. This is typical for the first half of the year in terms of taxonomic composition.
- A centric diatom bloom occurred in Cape Cod Bay in February, but was not observed in Massachusetts Bay.
- The *Phaeocystis pouchetii* bloom in April, 2001 was much less abundant than the bloom of this species during the same period the previous year. The 2001 *Phaeocystis* bloom was also a departure from the 3-year cycle for these blooms that had been observed during the baseline period (1992-2000).
- There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – June, 2001, other than the April bloom of *Phaeocystis pouchetii*. While the dinoflagellate *Alexandrium tamarense* and the diatom of *Pseudo-nitzschia pungens* were recorded, they were only present in very low abundance. None of the nuisance algae caution thresholds were exceeded during this period.
- Total zooplankton abundance did not increase from February through July as usual, and zooplankton counts were considerably lower than for the same period in the previous year. Zooplankton assemblages during the first half of 2001 were comprised of taxa recorded for the same time of year in previous years.
- Zooplankton assemblages during the first half of 2001 were comprised of taxa recorded for the same time of year in previous years.

WF011 **Station N04**

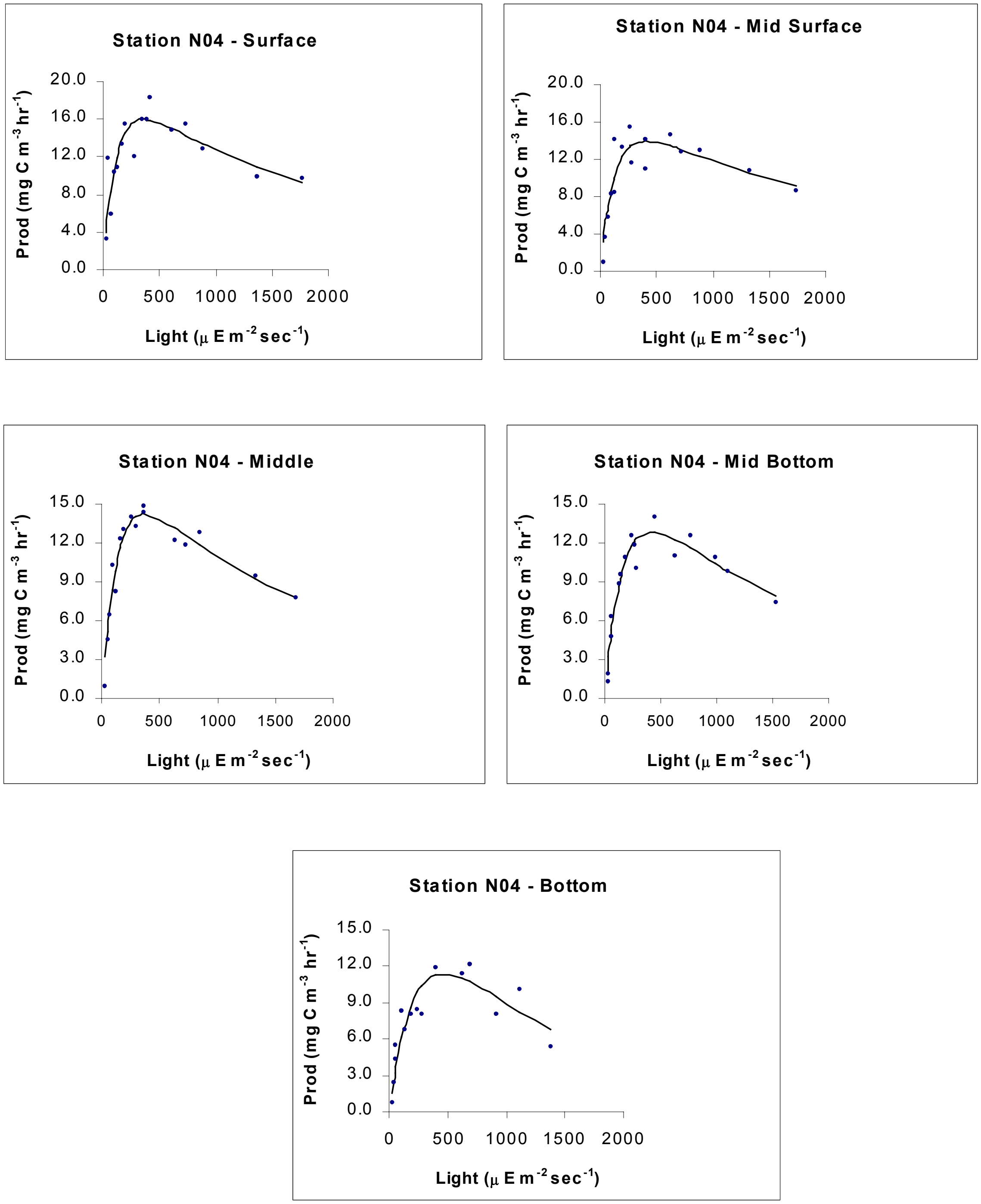


Figure 5-1. An example photosynthesis irradiance curve from station N04 collected February 2001

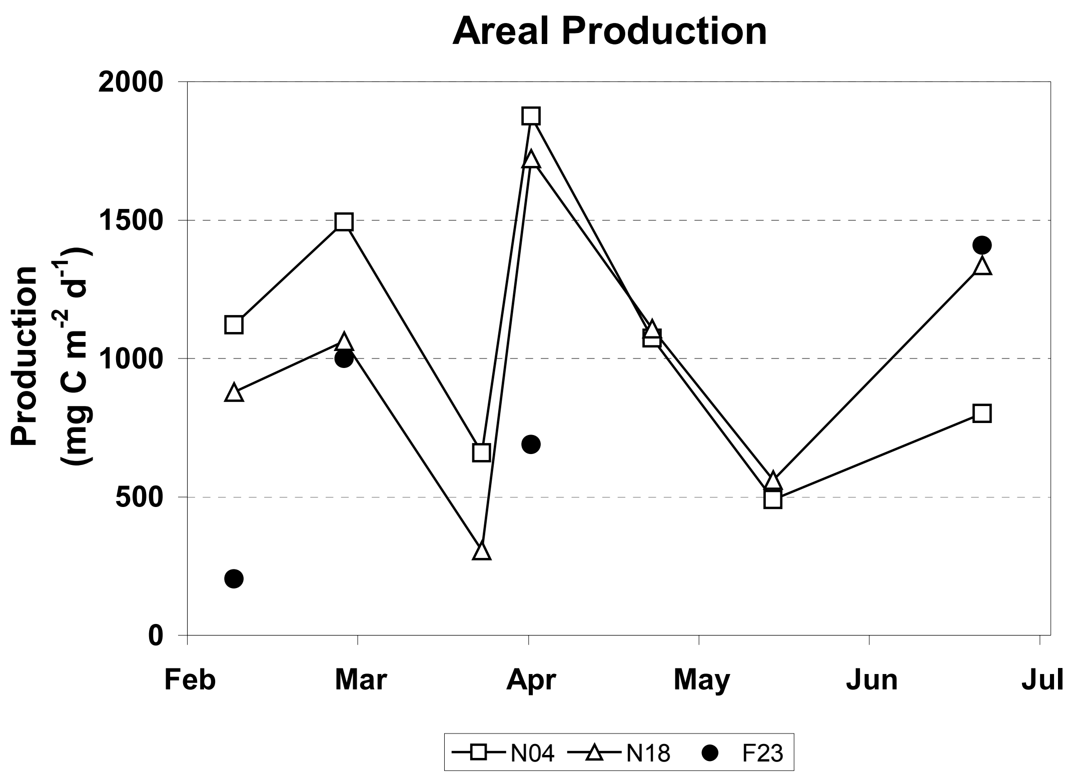


Figure 5-2. Time series of areal production (mg C m^{-2} d^{-1}) for stations N04, N18 and F23

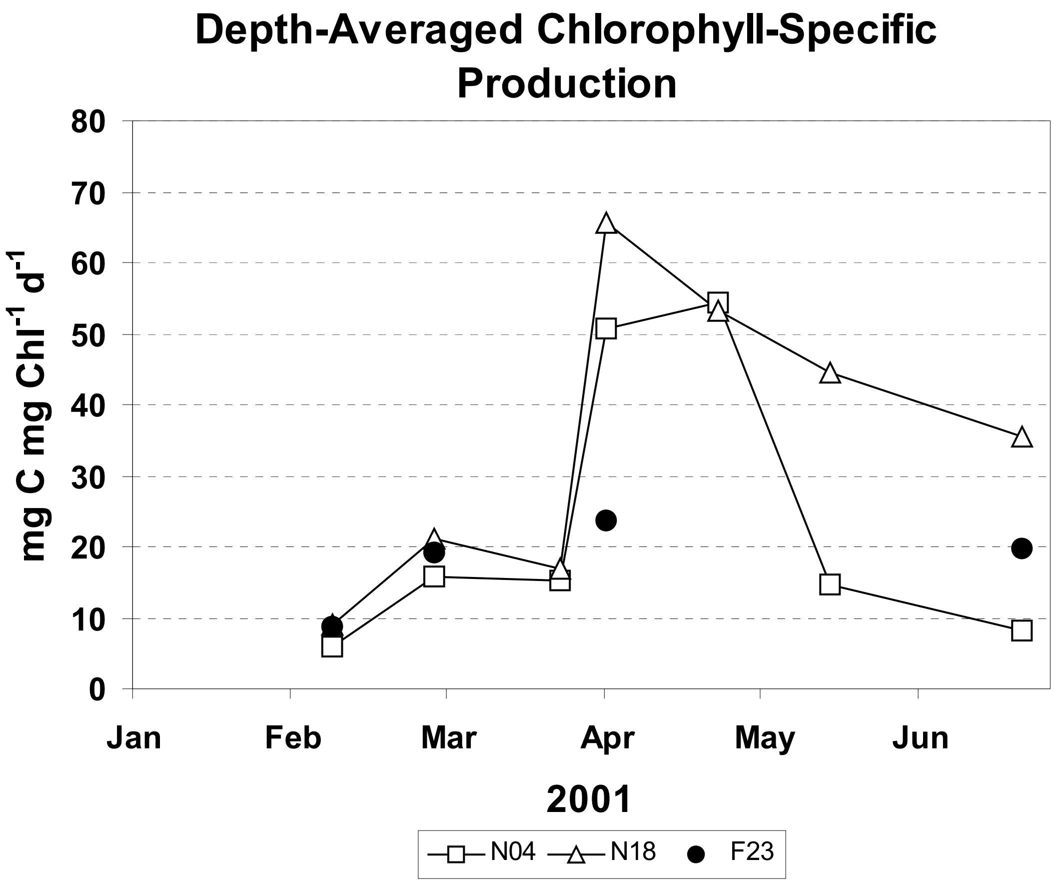


Figure 5-3. Time series of depth-averaged chlorophyll-specific production (mg C mg Chl a^{-1} d^{-1}) for stations N04, N18 and F23

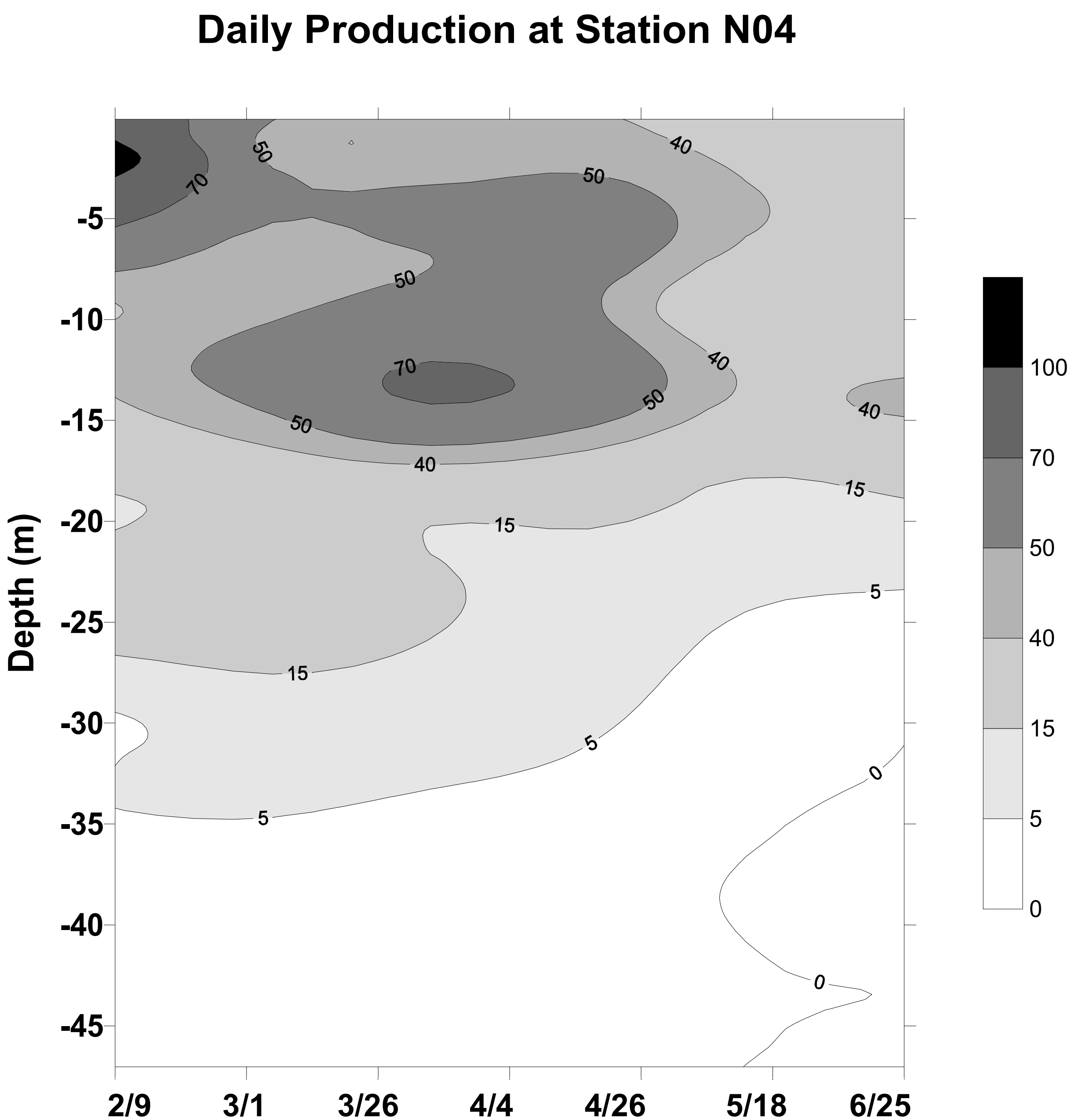


Figure 5-4. Time-series of contoured daily production ($mgCm^{-3}d^{-1}$) over depth at station N04

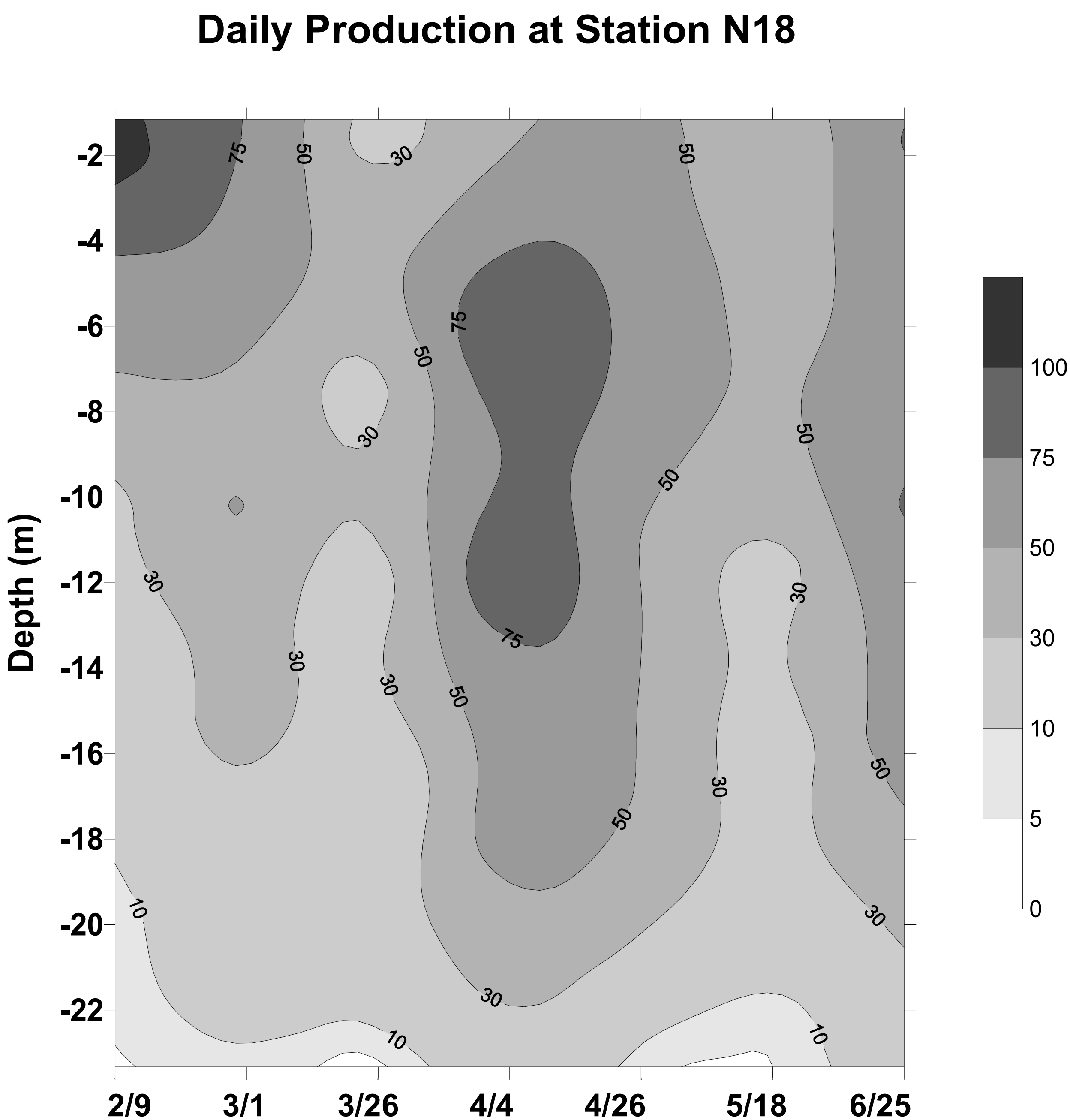


Figure 5-5. Time-series of contoured daily production ($mgCm^{-3}d^{-1}$) over depth at station N18

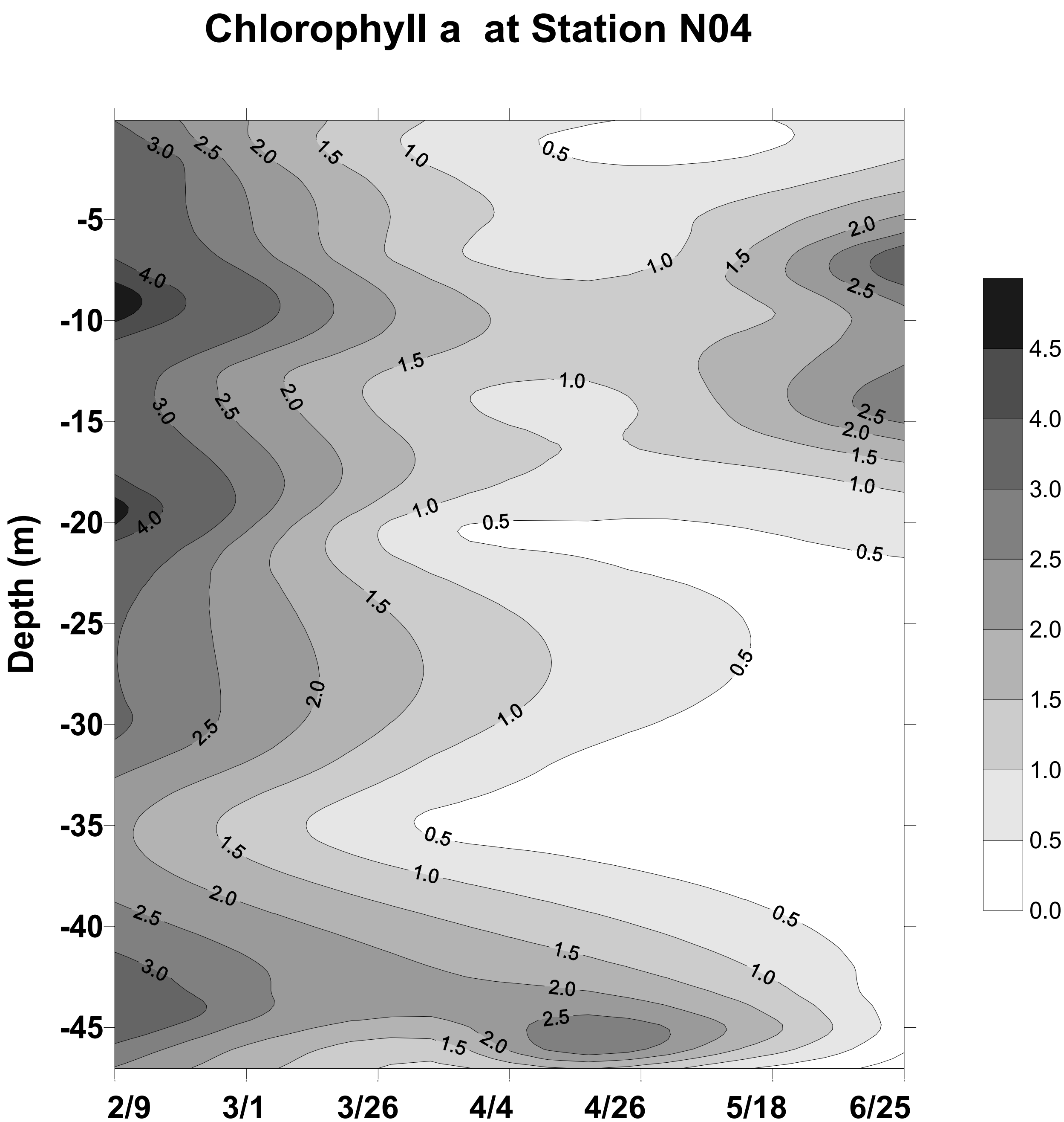


Figure 5-6. Time-series of contoured chlorophyll *a* concentration (μgL^{-1}) over depth at station N04

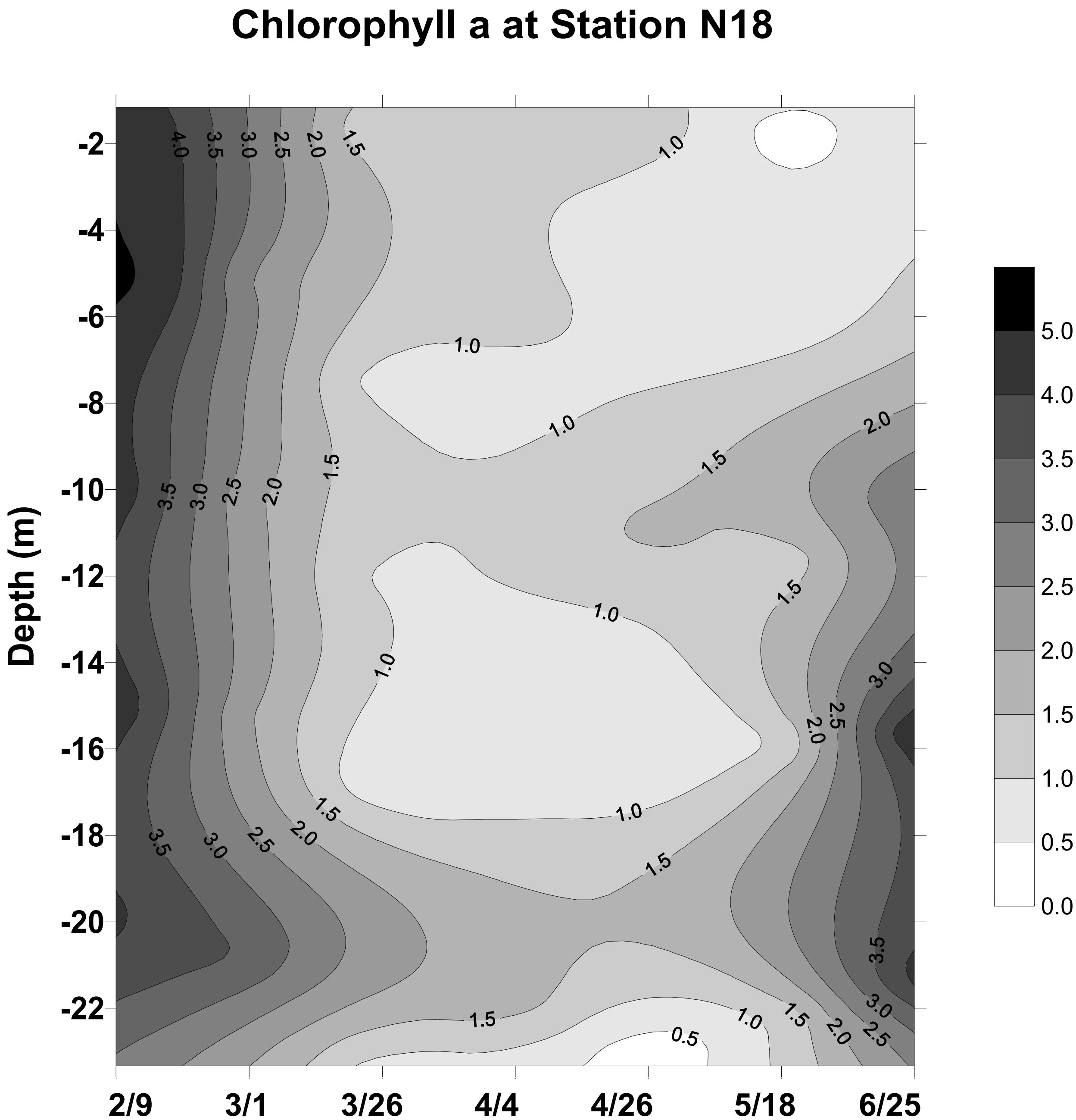


Figure 5-7. Time-series of contoured chlorophyll *a* concentration (μgL^{-1}) over depth at station N18

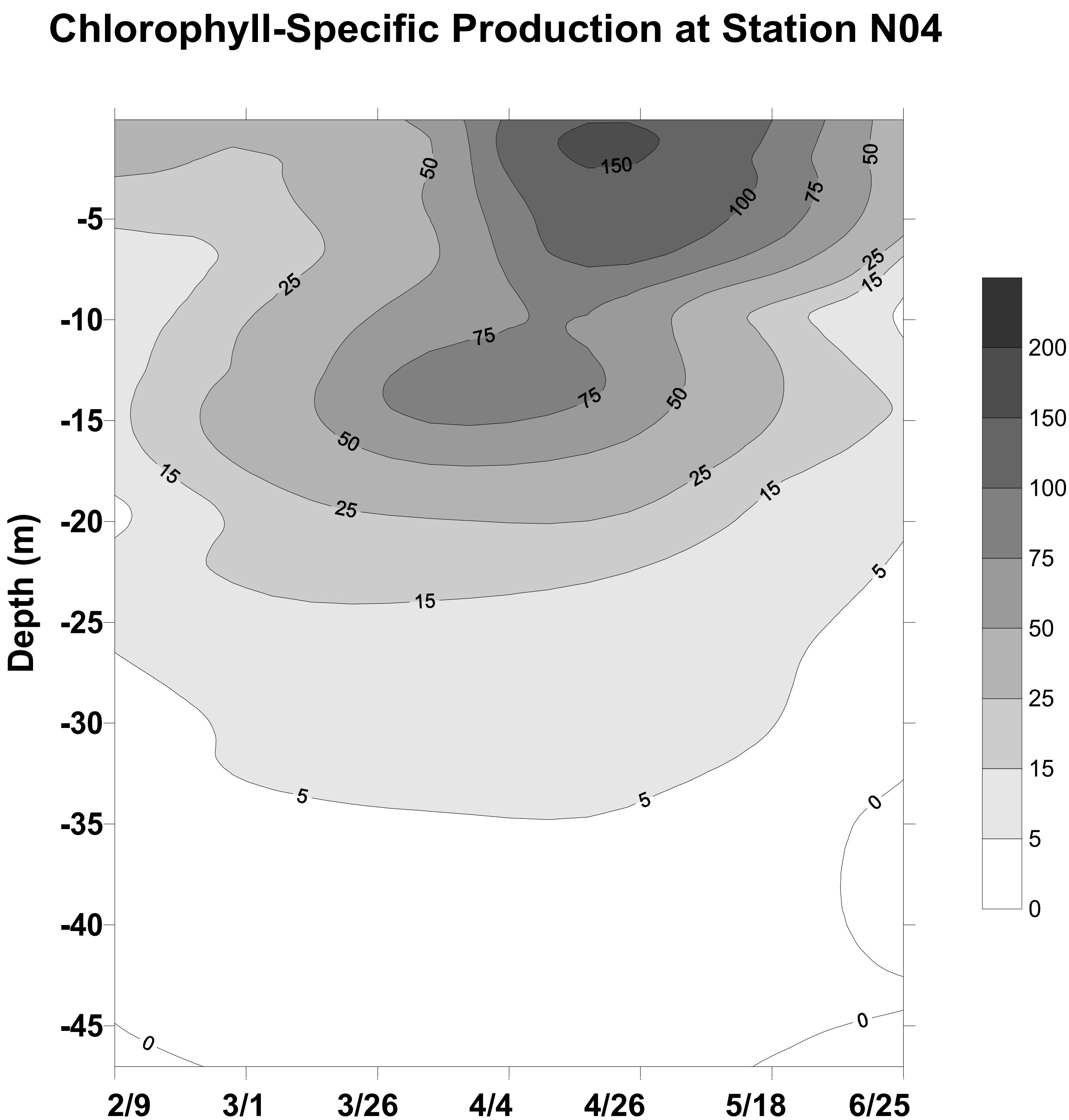


Figure 5-8. Time-series of contoured chlorophyll-specific production ($mgCmgChla^{-1}d^{-1}$) over depth at station N04

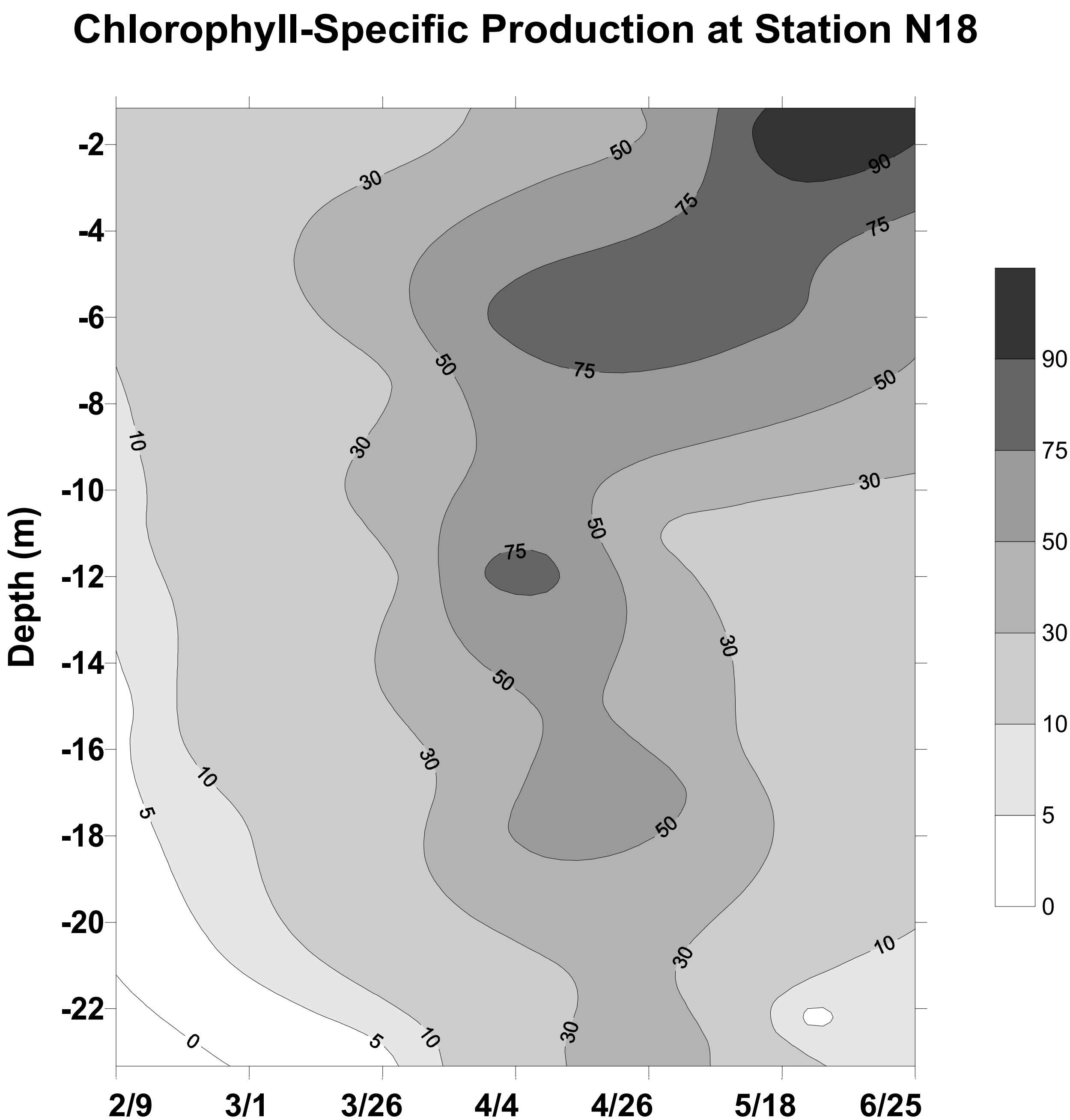


Figure 5-9. Time-series of contoured chlorophyll-specific production ($mgCmgChla^{-1}d^{-1}$) over depth at station N18

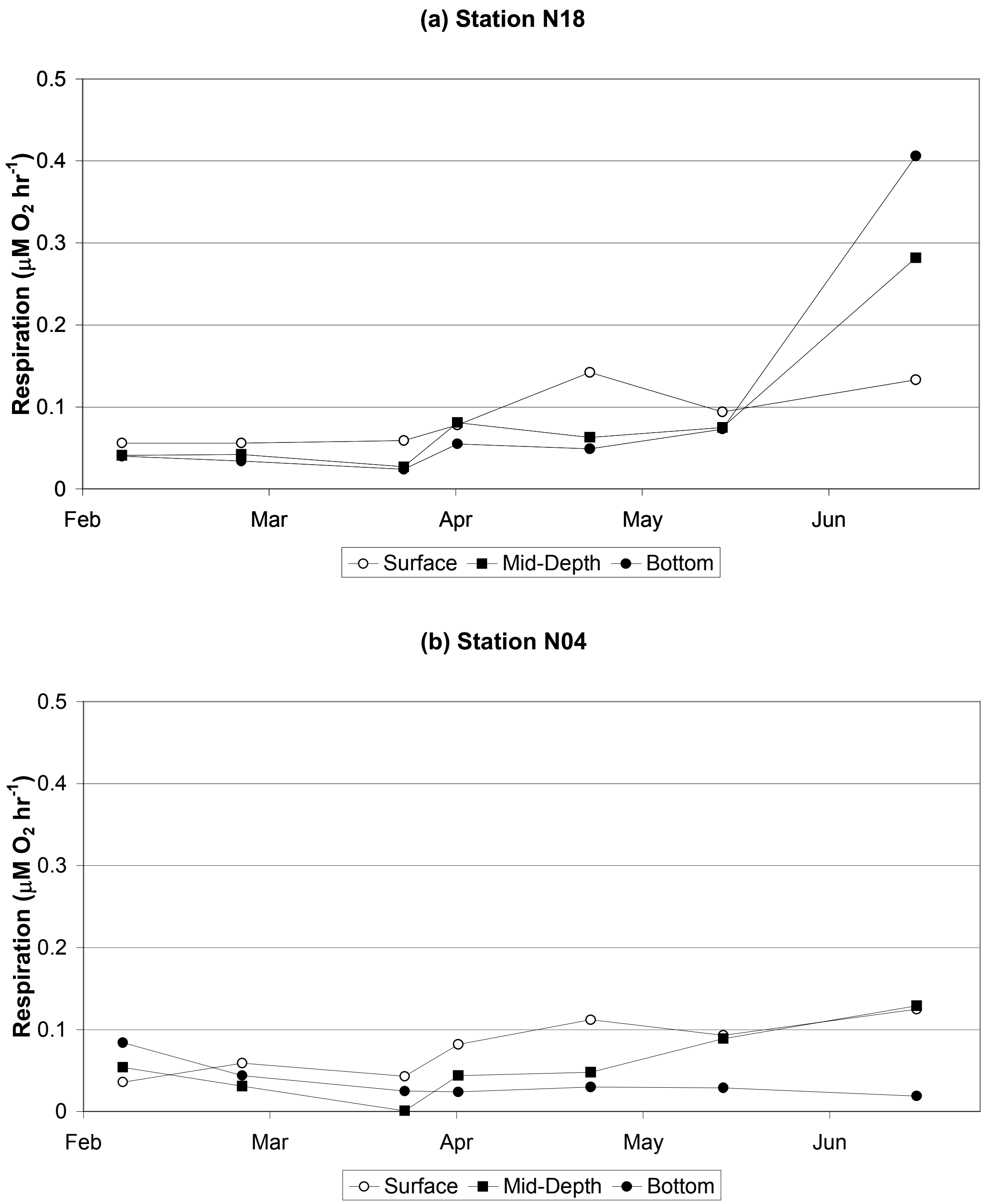
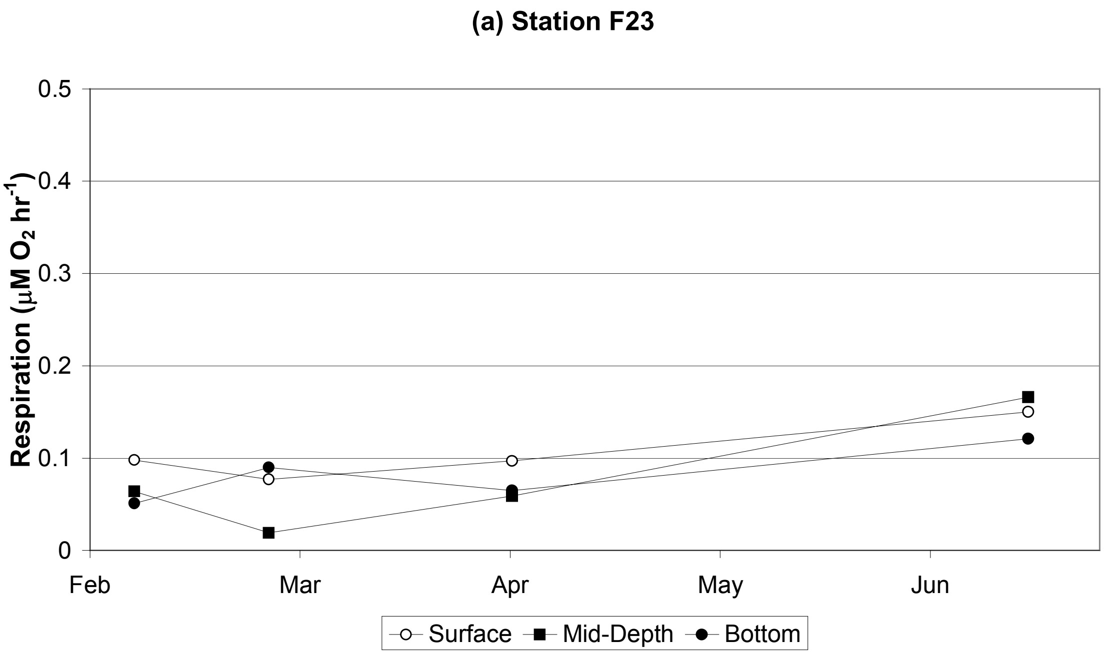


Figure 5-10. Time-series plots of respiration (μMO_2hr^{-1})stations N18 and N04



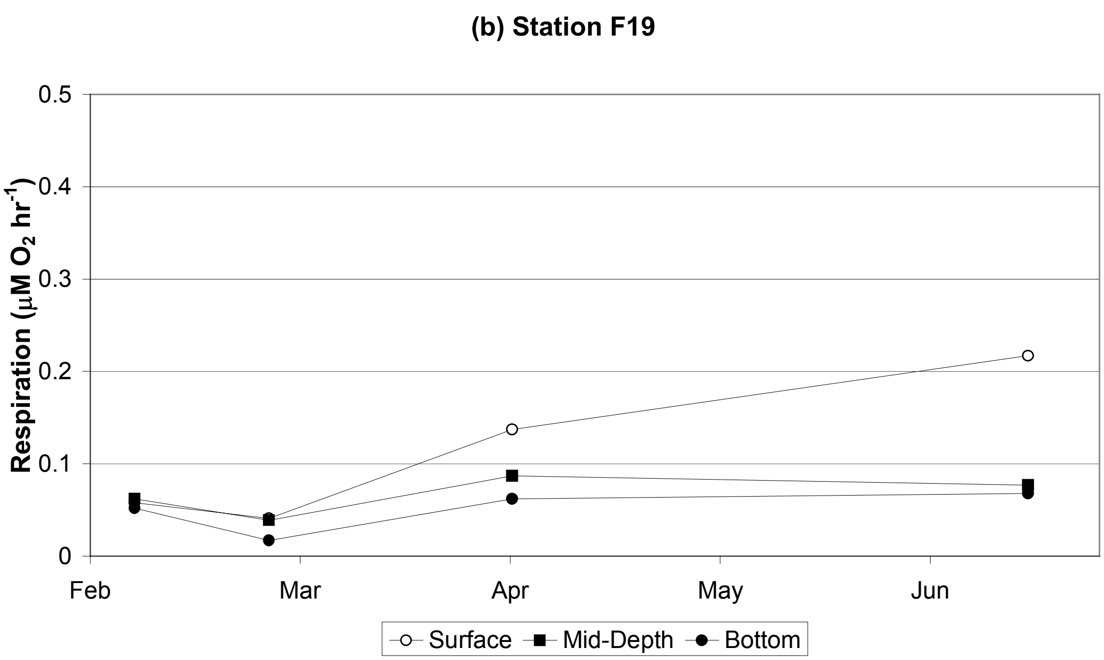
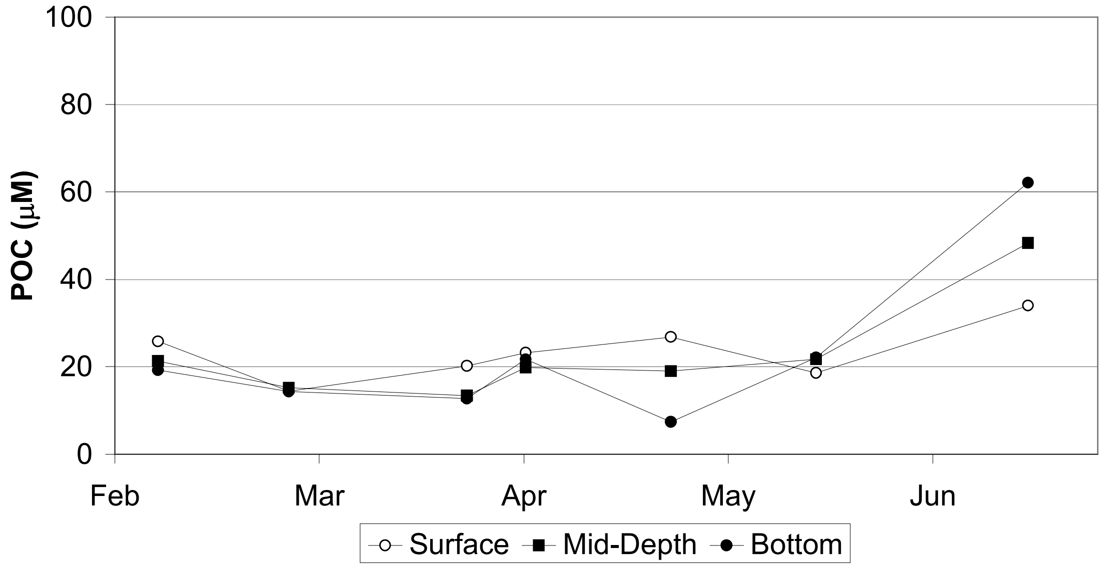


Figure 5-11. Time-series plots of respiration (μMO_2hr^{-1}) stations F23 and F19

(a) Station N18



(b) Station N04

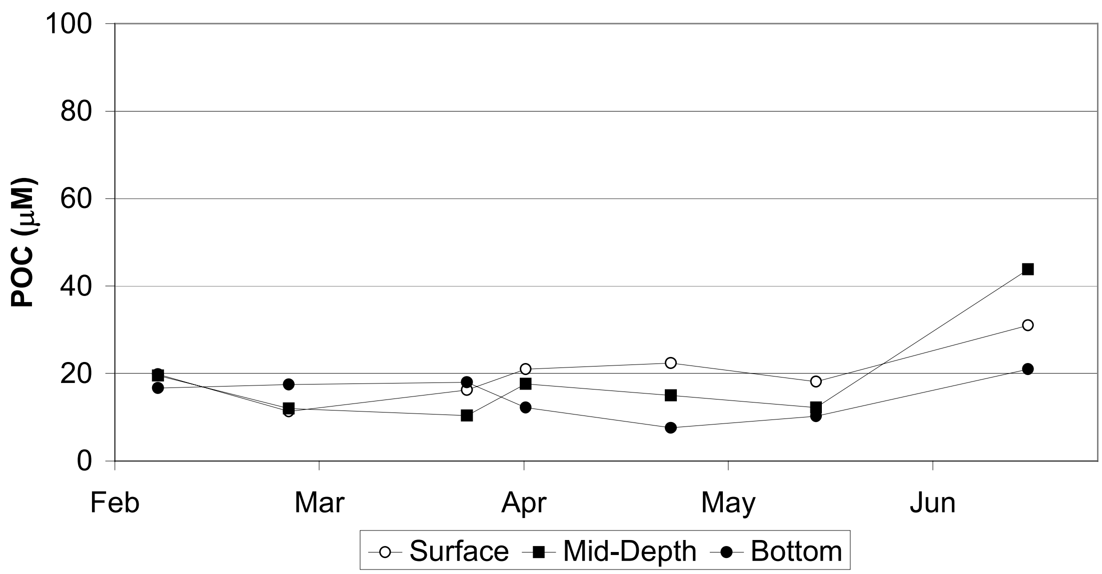
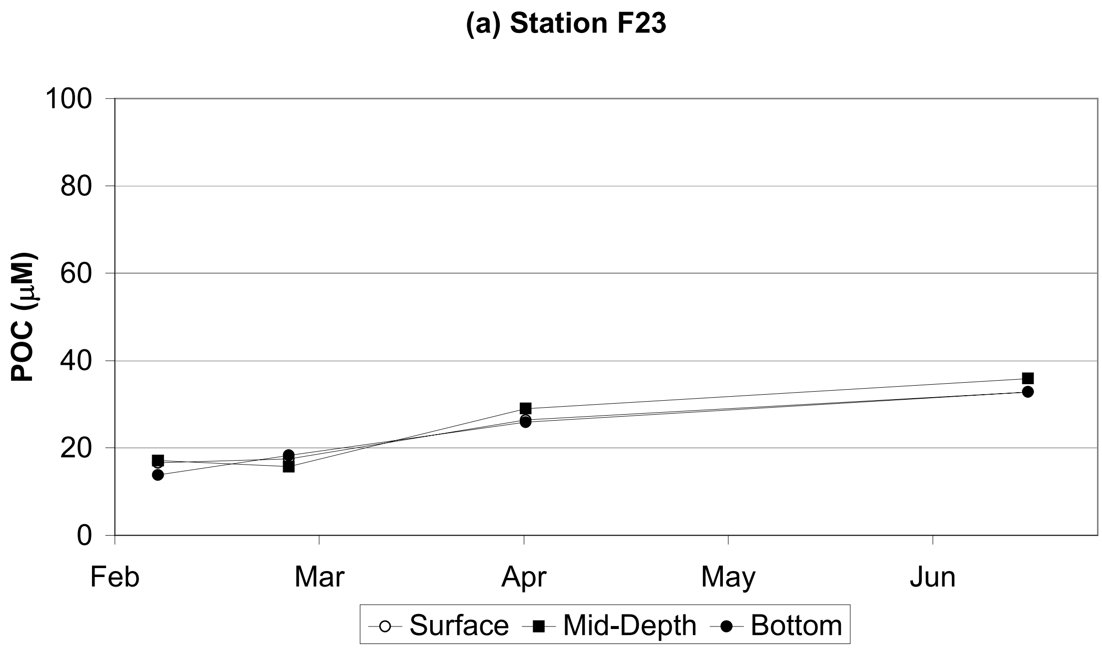


Figure 5-12. Time-series plots of POC (μMC) at stations N18 and N04



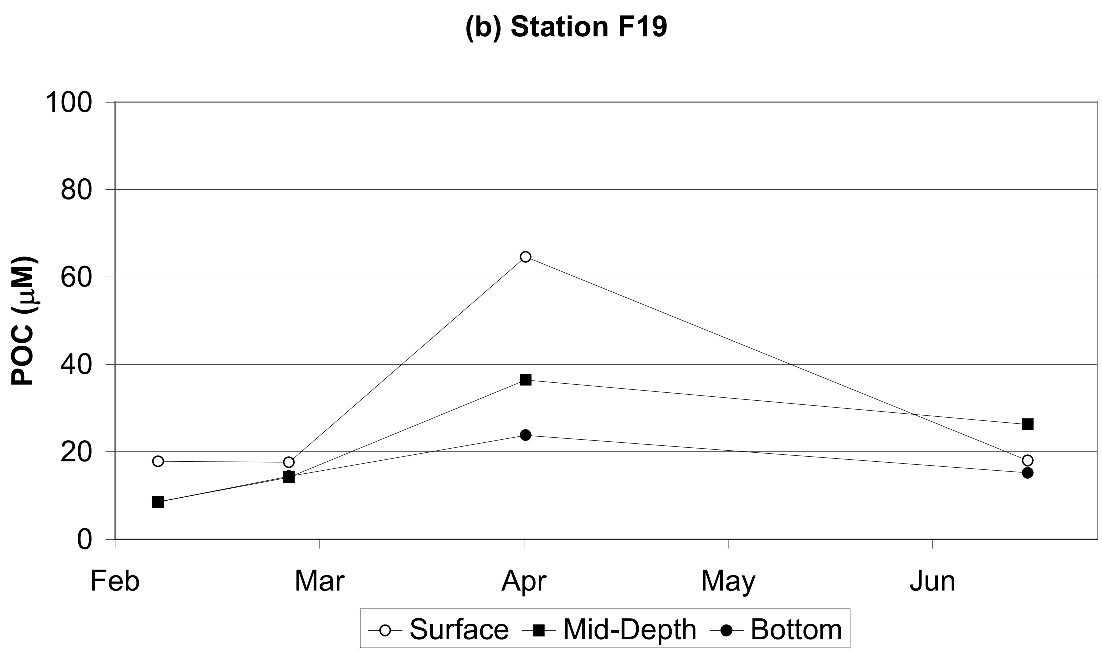
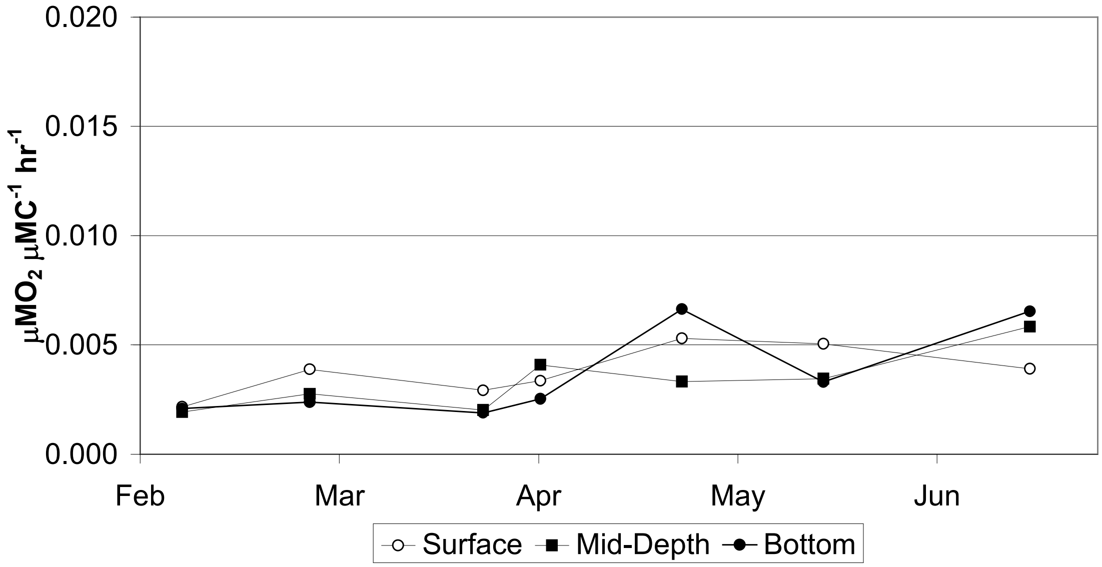


Figure 5-13. Time-series plots of POC (μMC) at stations F23 and F19

(a) Station N18



(b) Station N04

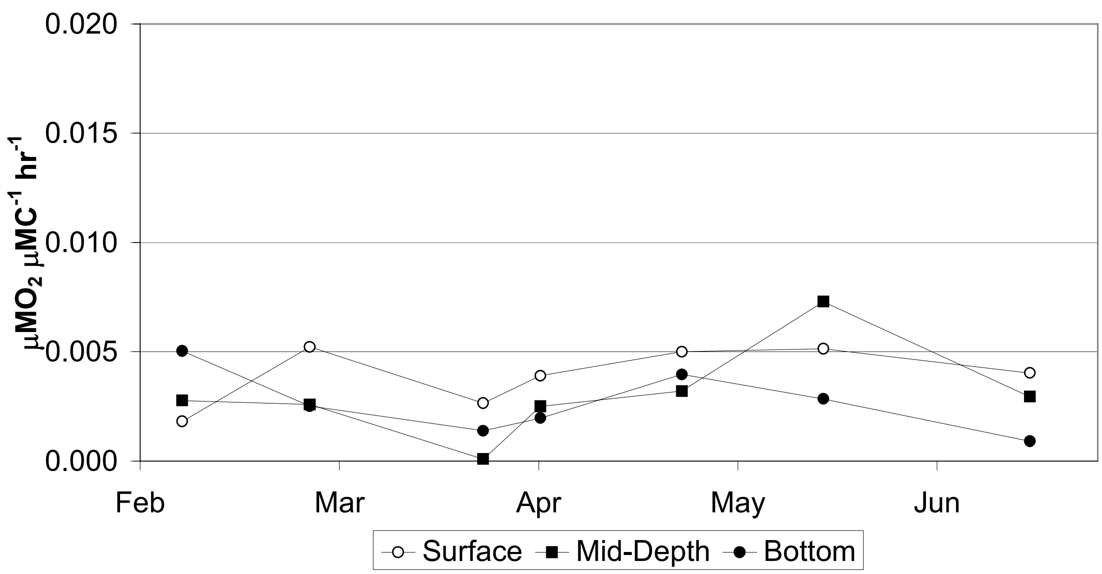
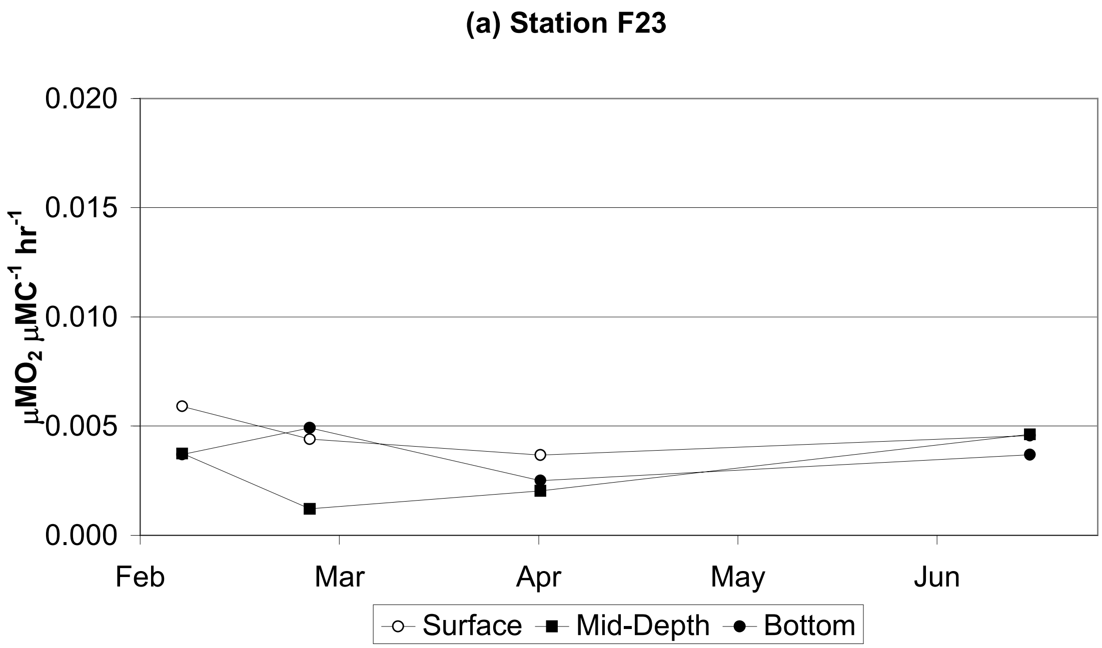


Figure 5-14. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations N18 and N04



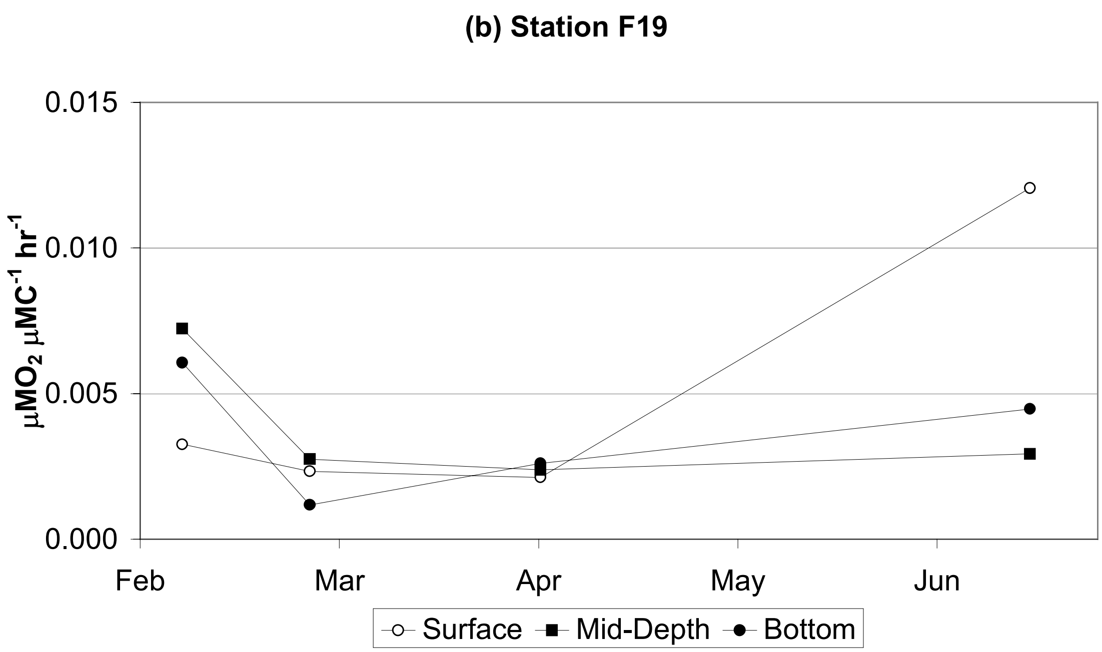


Figure 5-15. Time-series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations F23 and F19

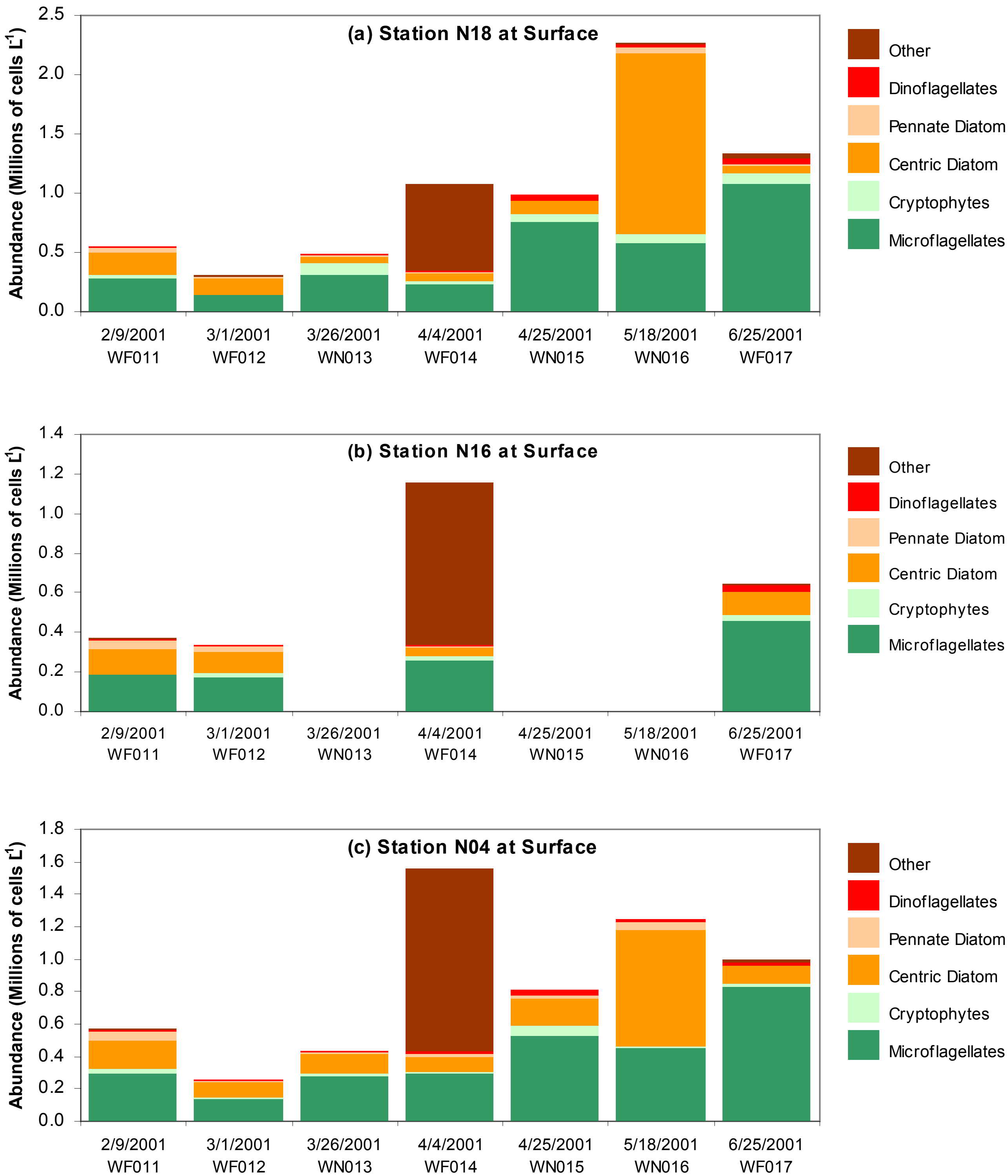


Figure 5-16. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Surface Samples

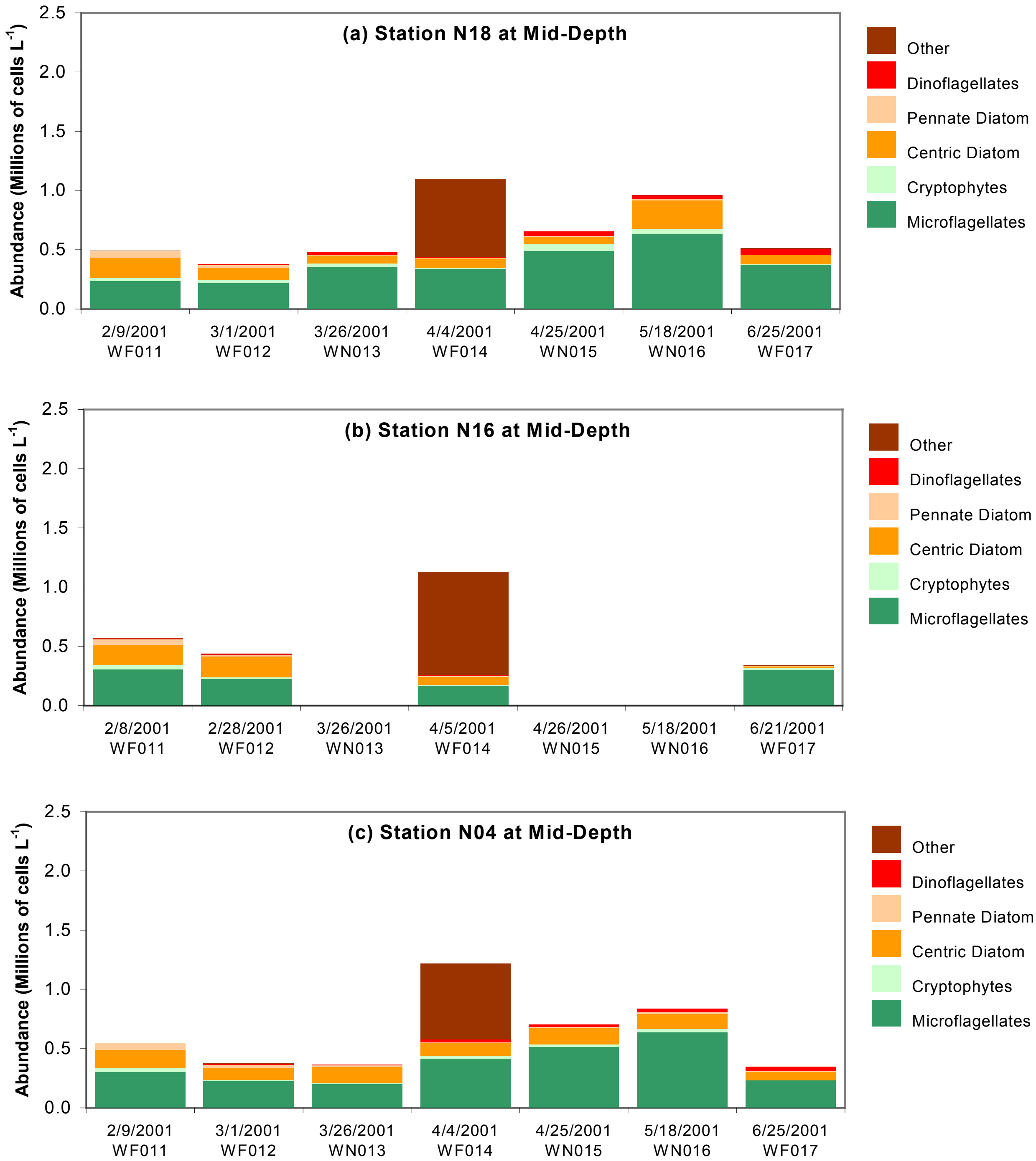


Figure 5-17. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Mid-Depth Samples

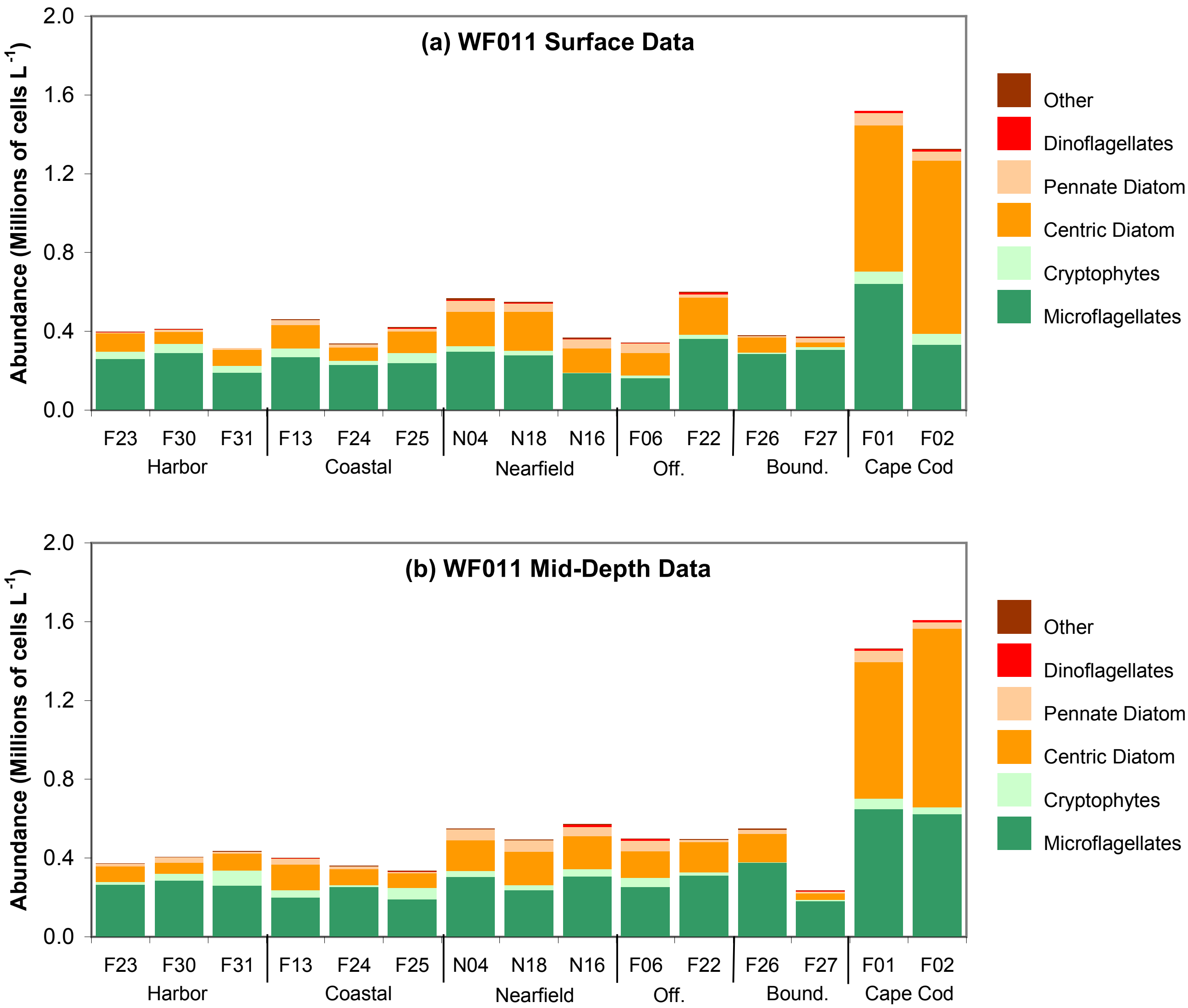
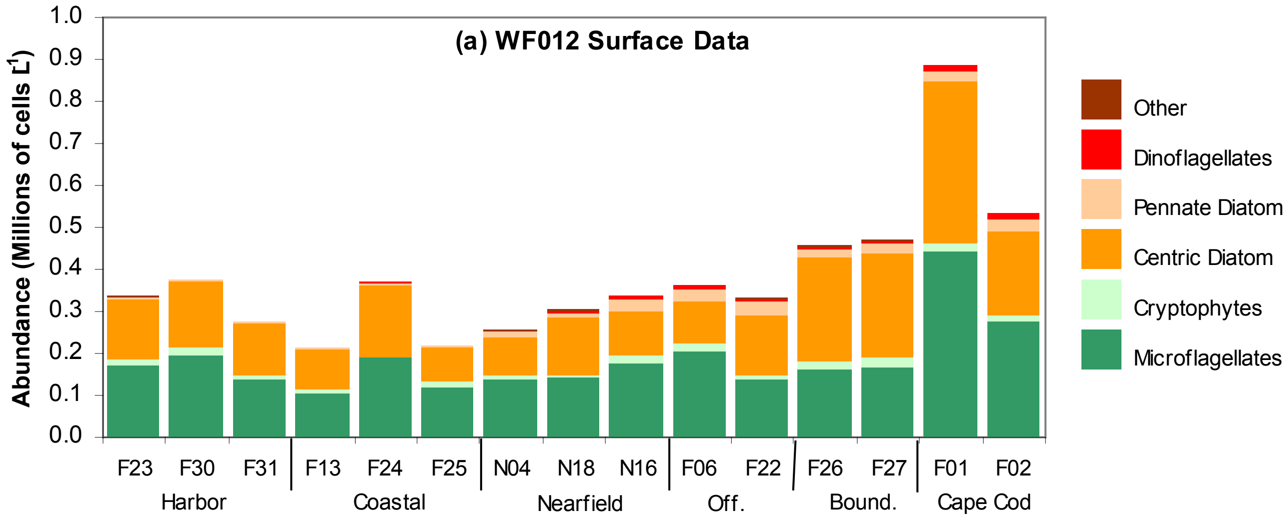


Figure 5-18. Phytoplankton Abundance by Major Taxonomic Group – WF011 Farfield Survey Results (February 7 – 12)



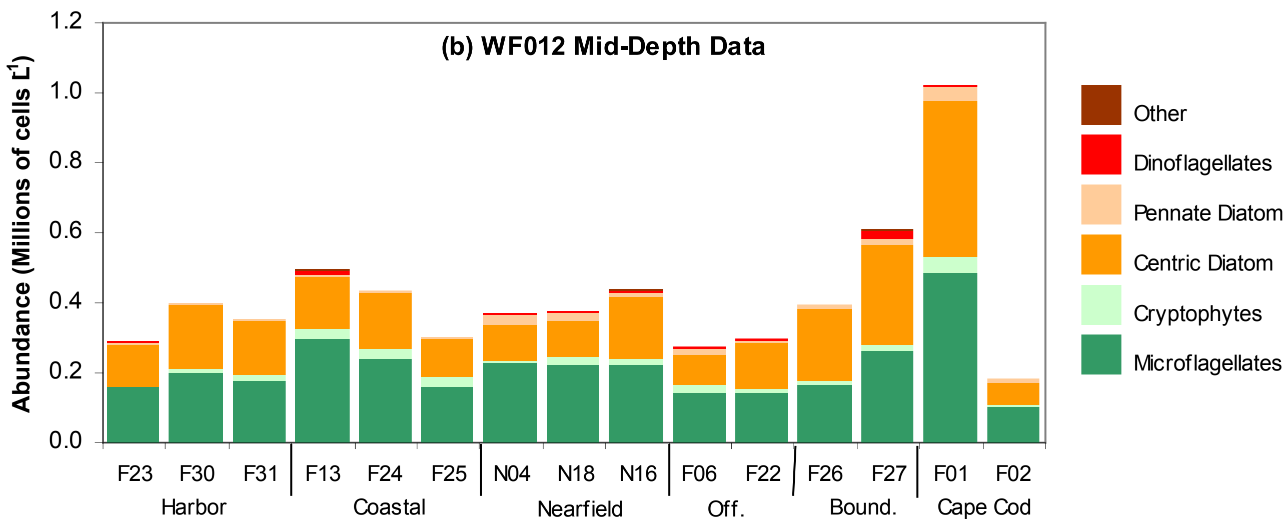


Figure 5-19. Phytoplankton Abundance by Major Taxonomic Group – WF012 Farfield Survey Results (February 27 – March 2)

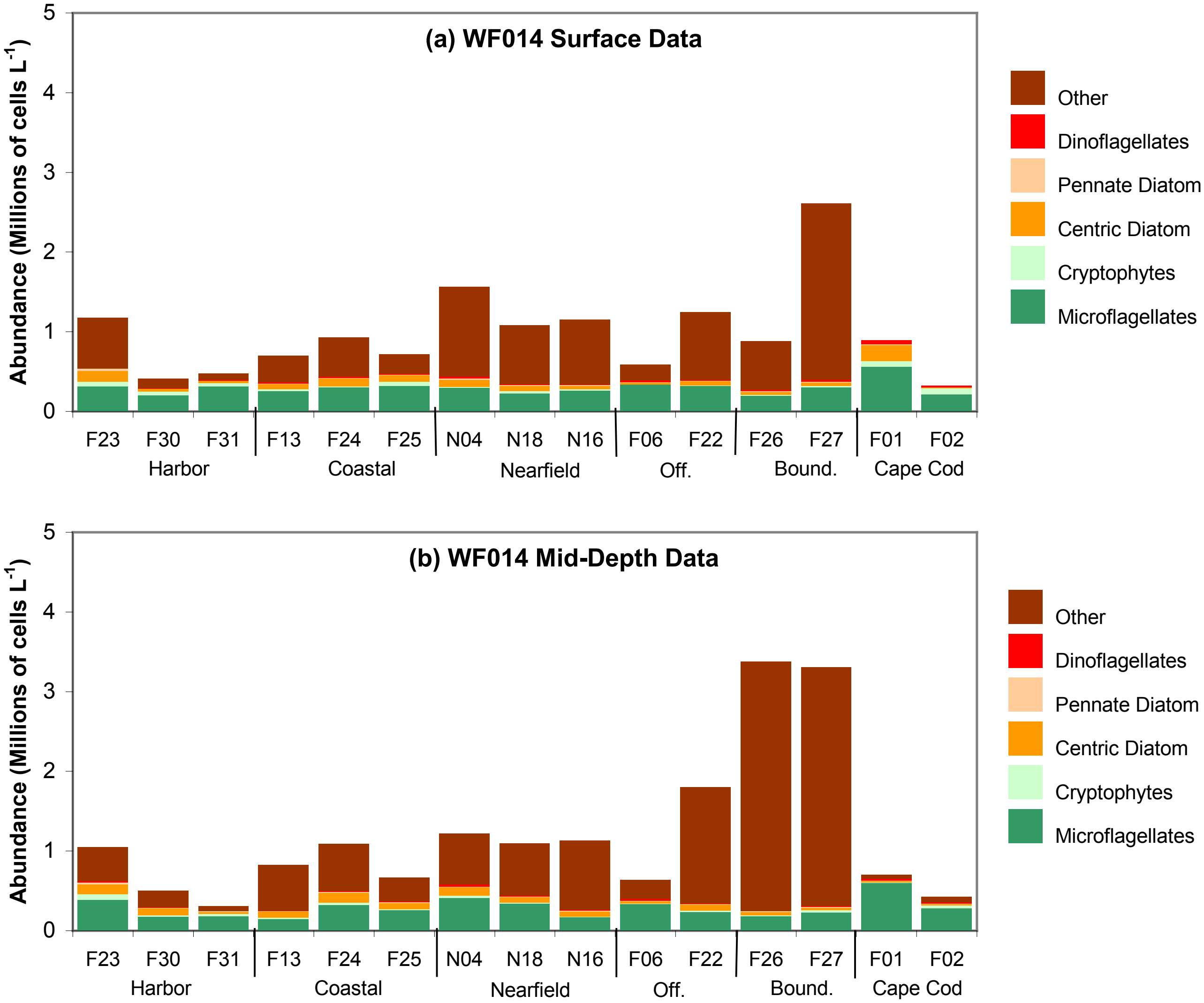


Figure 5-20. Phytoplankton Abundance by Major Taxonomic Group – WF014 Farfield Survey Results (April 4 – 9)

Figure 5-21. Phytoplankton Abundance by Major Taxonomic Group – WF017 Farfield Survey Results (June 19 – 25)

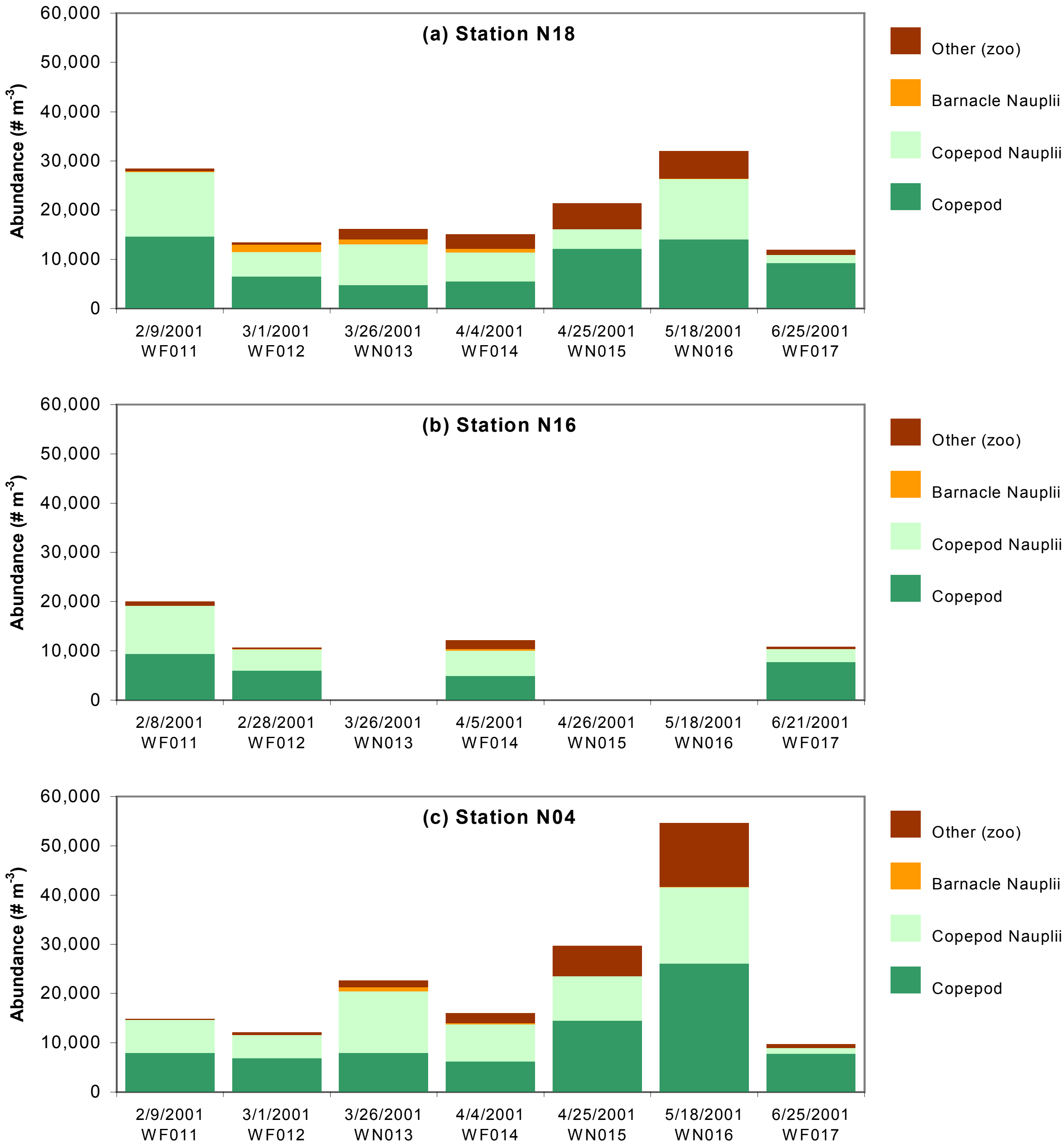


Figure 5-22. Zooplankton abundance by major taxonomic group at stations N18, N16 and N04.

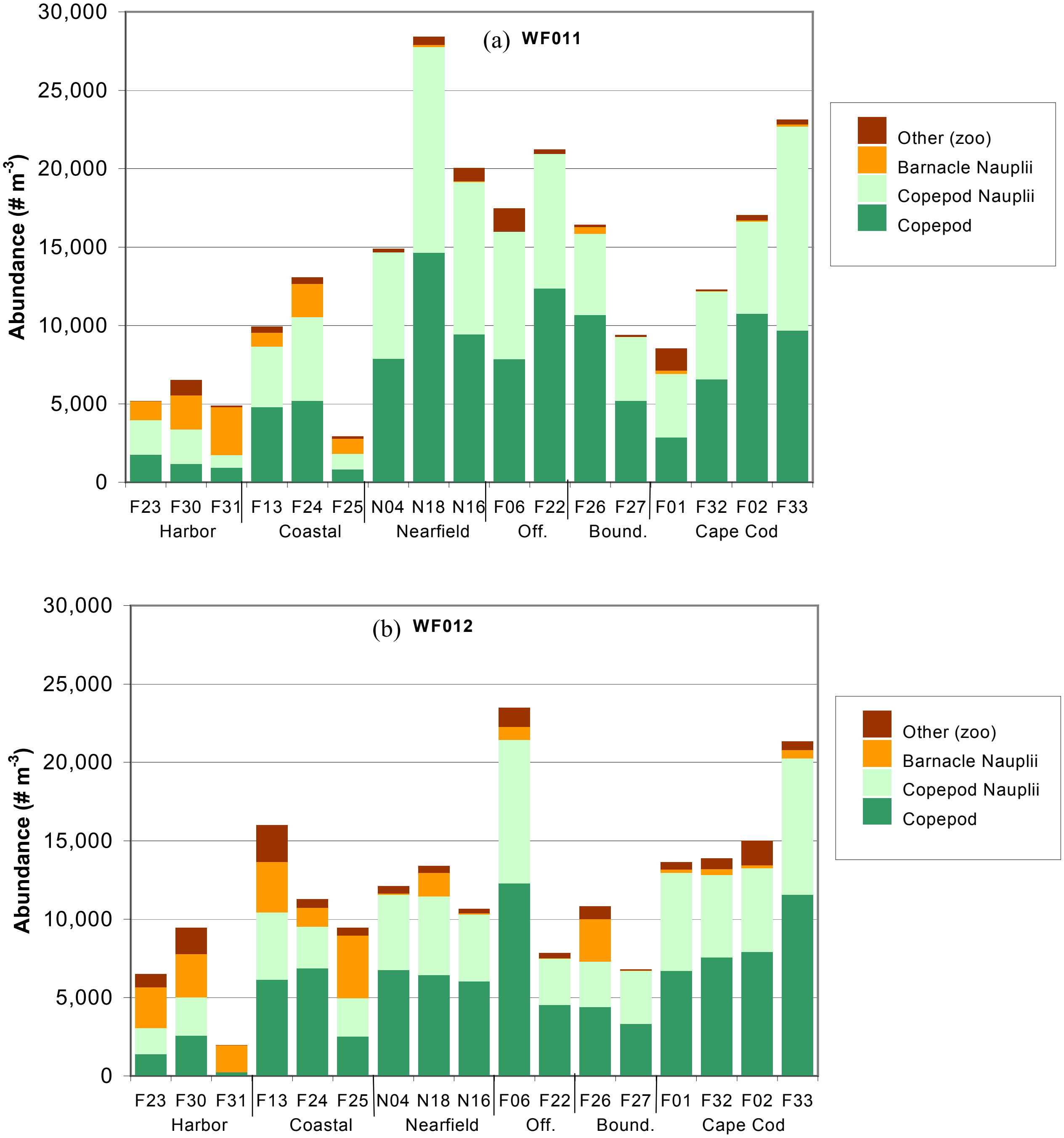
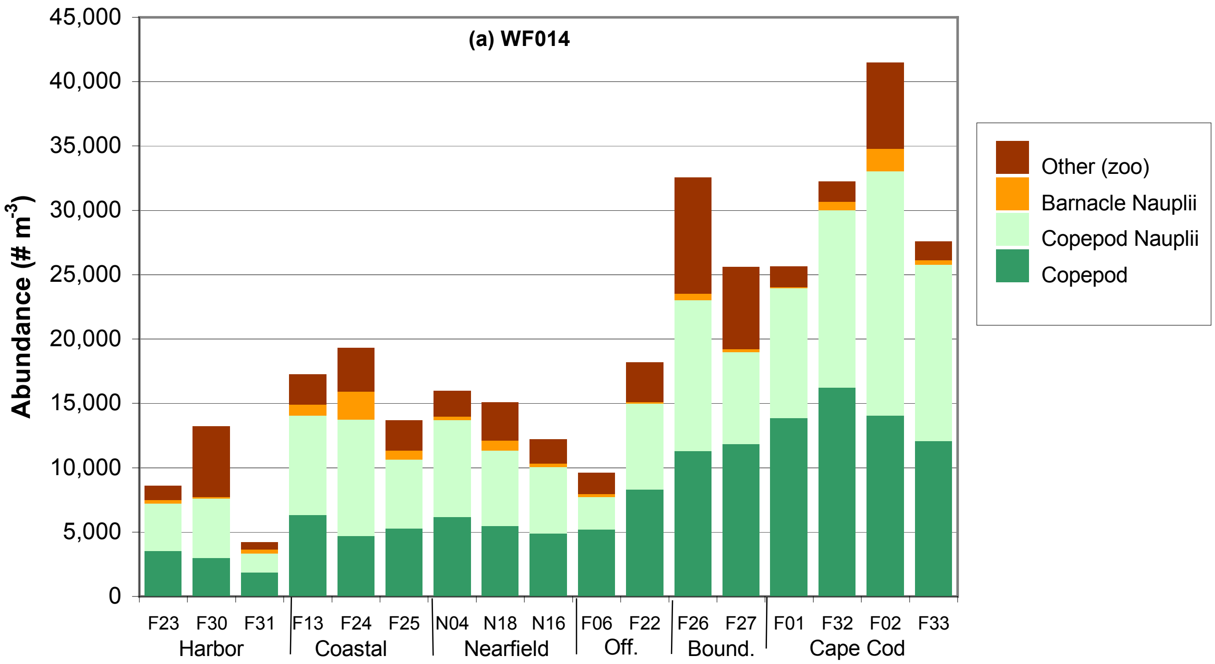


Figure 5-23. Zooplankton abundance by major taxonomic group during (a) WF011 and (b) WF012 farfield surveys



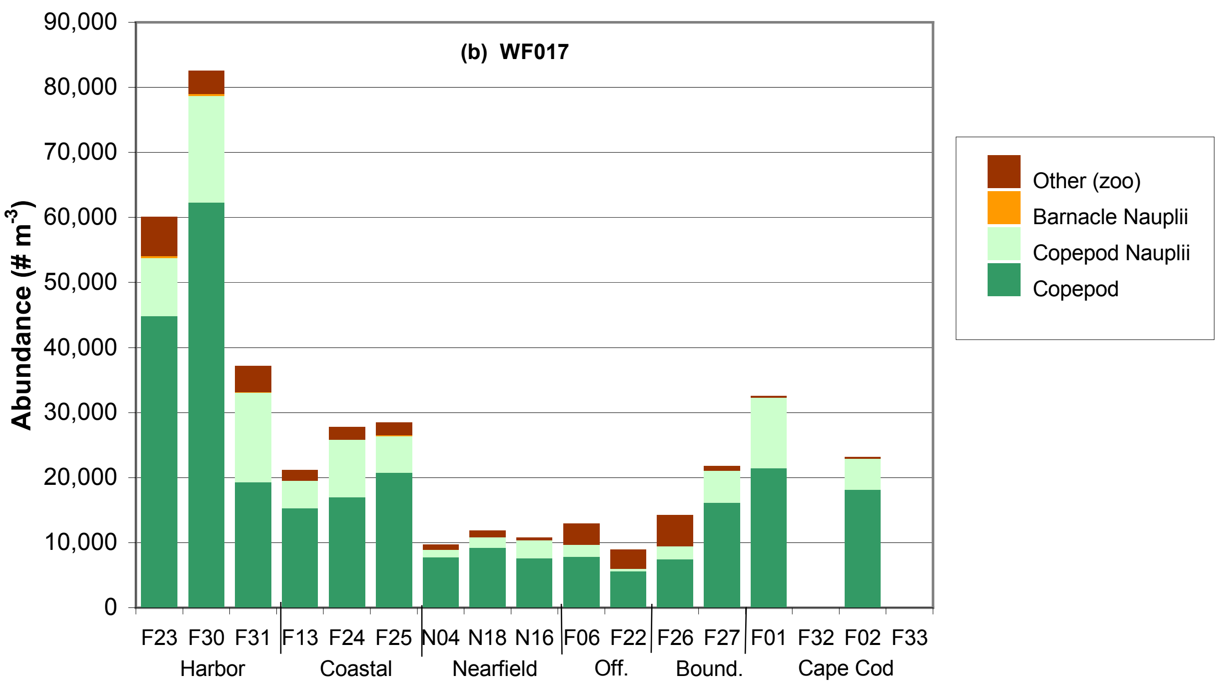


Figure 5-24. Zooplankton abundance by major taxonomic group during (a) WF014 and (b) WF017 farfield surveys

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The winter to spring transition in Massachusetts and Cape Cod Bays is characterized by a typical series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 2001 although no major phytoplankton bloom was observed in Massachusetts Bay. There was, however, a winter/spring bloom of centric diatoms in Cape Cod Bay and a minor bloom of *Phaeocystis pouchetii* that was most prominent in northeastern Massachusetts Bay. With the lack of a major bloom, productivity and chlorophyll concentrations remained relatively low throughout this time period and surface waters across much of the region were not depleted with respect to nutrients until June. This section presents a summary of these events and the integrated physical, biological, and chemical trends discussed in previous sections.

In the nearfield, the water column had begun to stratify in late March at the deeper eastern nearfield stations, but remained well mixed further inshore. Stratification was observed during the April combined survey in Boston Harbor, offshore, and boundary stations. The development of stratification at these stations was driven by a decrease in surface salinity due to March/April runoff, as surface and bottom water temperatures remained relatively unchanged. At coastal and Cape Cod Bay stations, density and salinity decreased from early March to April, but to similar degrees in both surface and bottom waters resulting in weaker April stratification. In early April, a localized mixing event in the nearfield was observed and may have been related to increased flow from the outfall discharge as a result of late March rain events. By late April, the water column had become weakly stratified across all of the nearfield area. By June, surface water temperatures had increased by >10°C throughout the bays and there continued to be a relatively large salinity gradient. These conditions resulted in a strong density gradient in Cape Cod Bay and offshore and boundary areas of Massachusetts Bay.

The nutrient data for February to June 2001 generally followed the "typical" progress of seasonal events in Massachusetts and Cape Cod Bays. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring 'diatom bloom' reduced nutrient concentrations in Cape Cod Bay surface waters in February. The minor winter/spring *Phaeocystis* bloom in Massachusetts Bay in early April did not lead to reduced nutrient concentrations except at boundary station F26 and F27 where the *Phaeocystis* abundance was highest. Massachusetts Bay nutrient concentrations decreased from early February through April, but did not reach depleted levels in surface waters until June.

The transfer of effluent discharge from the harbor outfall to the Massachusetts Bay outfall on September 6, 2000 reduced the harbor signal of elevated nutrient concentrations (especially NH_4) that had been observed throughout the baseline period. Elevated concentrations of NO_3 and SiO_4 were still observed at the inner harbor station F30 due to riverine inputs. The effluent nutrient signal was clearly evident in the nearfield as elevated NH_4 and PO_4 concentrations. Ammonium concentrations continue to be a good tracer, albeit not a conservative tracer, of the effluent plume in the nearfield. High flow rates due to late March and June rain events appear to have influenced water quality measurements in the nearfield. In early April, the nearfield was less stratified than surrounding waters and elevated NH_4 concentrations were present in surface waters. In June, no anomalous salinity or density signal was observed in the nearfield, but elevated NH_4 (and PO_4) concentrations were measured in the surface waters suggesting that the plume had reached the surface.

Chlorophyll concentrations in the nearfield were relatively low in 2001 and the nearfield mean areal chlorophyll for winter/spring 2001 of 69 mg m^{-2} well below the caution threshold of 182 mg m^{-2}. Chlorophyll concentrations peaked in early February and were highest in Cape Cod Bay coincident with the winter/spring diatom bloom. Areal production at the two nearfield stations was relatively high during February surveys. Chlorophyll concentrations increased and productivity peaked (~1900 mg C m^{-2} d^{-1}) in the nearfield in early April, but there was no large increase in chlorophyll associated with the minor bloom of *Phaeocystis* in Massachusetts Bay. The 2001 winter/spring peak production rates were considerably lower than winter-spring bloom maxima for 2000 when values of 2882 – 4017 mg C m^{-2} d^{-1} were observed.

In general, Boston Harbor exhibits a gradual pattern of increasing areal production from winter through summer rather than the distinct winter-spring peaks observed at the nearfield sites. In 2001 the pattern for station F23 did not conform to this description as production values increased from February through March but decreased in April before reaching the seasonal maximum in June (1409 mg C m^{-2} d^{-1}). During previous years (1995-2000), peak areal productions at station F23 ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal production observed in 2001 was lower but the time of the peak (June) was the same.

DO concentrations in 2001 were within the range of values observed during previous years and followed the typical trends. Maximum concentrations occurred in February when the water column was well mixed. There was a slight increase in surface DO concentrations in April coincident with the peak in productivity. DO concentrations reached minima for this time period in June in most of Massachusetts and Cape Cod Bays, but bottom water DO concentrations in June 2001 were higher than those measured during the two previous years. There was an increase in bottom water DO concentrations at the boundary stations from April to June due to an influx of waters from the Gulf of Maine. The lack of a major winter/spring bloom in Massachusetts Bay and the regional influence of the Gulf of Maine led to relatively high bottom water DO concentrations in June. The lowest bottom water DO concentrations were found in Cape Cod Bay, which is not strongly influenced by the Gulf of Maine and had a winter/spring diatom bloom in February. Respiration rates in 2001 were low compared to 1999 and 2000, which is not surprising as both years had significant winter/spring blooms. The low respiration rates observed during the winter/spring of 2001 were likely related to the relatively low concentrations of organic carbon and expected low rate of transfer of carbon to bottom waters because of the lack of a substantial bloom in 2001. The main exception to the low respiration rates was observed in June at station N18 where bottom water respiration was 0.4 μM O_2 hr^{-1}. This was coincident with a very high POC concentration (62 μM) resulting in a relatively high carbon-specific respiration rate. This indicates that not only was POC available, but it was also more labile. The elevated POC concentrations may have been due to effluent from the nearby (~2 km) outfall. The effect of these physical and biological factors and the influence of the outfall on nearfield respiration rates will be evaluated in more detail in the 2001 Annual Report.

Whole-water phytoplankton assemblages were dominated by unidentified microflagellates and several species of centric diatoms except during the April *Phaeocystis* bloom. This is typical for the first half of the year in terms of taxonomic composition. The *Phaeocystis pouchetii* bloom in April 2001 was much less abundant than the bloom of this species during the same period the previous year. The 2001 *Phaeocystis* bloom was also a departure from the 3-year cycle for these blooms that had been observed during the baseline period (Libby *et al*., 2001). There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during this time period, other than the April bloom of *Phaeocystis pouchetii*. While the dinoflagellate *Alexandrium tamarense* and the diatom of *Pseudo-nitzschia pungens* were recorded, they were present in very low abundance.

Total zooplankton abundance did not increase from February through July as has usually been the case, and zooplankton counts were considerably lower than for the same period the previous year. The relatively low abundance of zooplankton may have been due to bottom-up control because phytoplankton was relatively sparse. Zooplankton assemblages during the first half of 2001 were comprised of taxa recorded for the same time of year in previous years.

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions. The water quality parameters included as thresholds are annual and seasonal chlorophyll levels in the nearfield, dissolved oxygen concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, and nuisance algae (*Alexandrium*, *Phaeocystis*, and *Pseudo-nitzschia*). For the winter/spring of 2001, data are only compared versus the thresholds for winter/spring areal chlorophyll and the nuisance algae. The nearfield mean areal chlorophyll value was 69 mg m^{-2} for winter/spring 2001, which is well below the caution threshold of 182 mg m^{-2} and none of the nuisance algae thresholds were exceeded for winter/spring 2001.

A number of topics were called out in this report that will be discussed in greater detail in the 2001 annual water column report and the nutrient issues review including the following:

- Effect of physical, biological, and regional factors on bottom water DO concentrations in Massachusetts Bay. This will be evaluated in detail in the nutrient issues review and results will be included in the annual report to describe trends during this monitoring year.
- Continued observation of elevated ammonium concentrations and the potential effect on biological processes in the nearfield. Including the potential for incursions of the effluent plume into surface waters during stratified conditions.
- Potential influence of outfall on nearfield bottom water respiration rates and subsequent affect on dissolved oxygen concentrations.
- Evaluation of controlling factors inhibiting or contributing to the occurrence of winter/spring blooms in Massachusetts Bay.
- The departure from the apparent 3-year cycle of *Phaeocystis* blooms that was observed in Massachusetts Bay during the baseline period and the regional expression of these blooms (*i.e.* Gulf of Maine).

7.0 REFERENCES

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